U.S. DEPARTMENT OF COMMERCE
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PB-287 081

Land Cultivation of Industrial Wastes and Municipal Solid Wastes: State-of-the-Art Study. Volume II Field Investigations and Case Studies

SCS Engineers, Long Beach, CA

Prepared for

Municipal Environmental Research Lab., Cincinnati, OH

Aug 78

United States
Environmental Protection
Agency

Municipal Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/2-78-140b
August 1978

PB 287081

Research and Development

Land Cultivation of Industrial Wastes and Municipal Solid Wastes

State-of-the Art Study

Volume II
Field Investigations and Case Studies

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TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-78-140b	2.	3. RECIPIENT'S ACCESSION NO. PB287081
4. TITLE AND SUBTITLE LAND CULTIVATION OF INDUSTRIAL WASTES AND MUNICIPAL SOLID WASTES: STATE-OF-THE-ART STUDY Volume II - Field Investigations and Case Studies		5. REPORT DATE August 1978 (Issuing Date) 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Tan Phung, Larry Barker, David Ross, and David Bauer		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS SCS Engineers 4014 Long Beach Boulevard Long Beach, California 90807		10. PROGRAM ELEMENT NO. 1DC618 11. CONTRACT/~~GRANT~~ NO. 68-03-2435
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory--Cin.,OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final, July 1976 to Jan. 1978 14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

Project Officer: Robert E. Landreth (513) 684-7871
See also Vol. 1, EPA-600/2-78-140a

16. ABSTRACT

A review of the available literature on land cultivation of industrial wastewater and sludge, and municipal solid waste was conducted. This review was supplemented by field investigations at 10 operating sites, including soil and vegetation analyses.

Soil is a natural environment for the inactivation and degradation of many waste materials through a variety of soil processes. Land cultivation is a disposal technique by which a waste is spread on and incorporated into the surface soil. Depending on waste characteristics, the disposal program can be either related to agriculture or solely a disposal practice.

Volume 1 is a technical summary and literature review. It contains information about land cultivation practices, waste characteristics and quantities, mechanisms of waste degradation, effects on soil properties and plants, regulations, site selection, operation, environmental impact assessment, site monitoring, site conceptual design, and case study summaries. Cited are 202 reference.

Volume 2 summarizes the results of field investigations and case studies. It covers four field studies, six case studies, and a section on nonstandard disposal or utilization techniques for hazardous wastes. Field data was collected to evaluate operational procedures, costs, environmental impacts, and problems associated with land cultivation at the individual sites.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Industrial wastes Refuse disposal Land reclamation Soil chemistry Soil microbiology Plant nutrition Plant physiology Waste disposal	Biodegradation Land application	13B

18. DISTRIBUTION STATEMENT Release unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 173
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE PC-A08 /MF-A01

☆ U. S. GOVERNMENT PRINTING OFFICE: 1978-757-140/1433 Region No. 5-II

EPA-600/2-78-140b
August 1978

LAND CULTIVATION OF INDUSTRIAL WASTES AND MUNICIPAL SOLID WASTES: STATE-OF-THE-ART STUDY

Volume II

Field Investigations and Case Studies

by

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Contract No. 68-03-2435

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U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

Soil has an enormous capability to assimilate waste materials. If managed properly, soil can often serve as a sink for a wide range of waste materials. Thus, land cultivation is truly a final disposal method whereby the waste is recycled on land.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory

ABSTRACT

This volume evaluates field data on the operational procedures, costs, environmental impacts, and problems associated with land cultivation of municipal refuse and industrial wastes.

Ten land cultivation sites were investigated, and composite soil and vegetation samples were collected at seven sites. Preliminary results indicated elevated concentrations of some heavy metals in surface soils and plant tissues from sites receiving refinery and tannery sludges. No significant changes were noted in the chemical properties of the soils or the elemental concentrations in plant tissues due to land cultivation of waste concentrated sulfuric acid, mixed chemical sludge, or shredded municipal refuse. The data was insufficient to assess the overall and long-term soil and vegetative impacts of land cultivation.

Case study reports include descriptions for each of the ten sites, coverage of the waste(s) cultivated, operational procedures and problems, and perceived environmental effects of land cultivation. Economic, equipment and personnel information are given for six sites. It is concluded that land cultivation equipment is similar to farming equipment, and the costs are comparable or lower than conventional acceptable disposal methods. Land cultivation has not resulted in environmental degradation at the sites studied; it may be a viable disposal method for many organic industrial wastes. Before selecting this method, all waste and site characteristics must be fully determined and proper site preparation and management techniques developed and implemented.

In addition, methods currently being employed for the nonstandard disposal (or utilization) of hazardous wastes were summarized.

This report was submitted in fulfillment of Contract No. 68-03-2435 by SCS Engineers under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period July 1976 to January 1978, and work was completed as of April 30, 1978.

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ACKNOWLEDGMENTS

The literature and case study reports are the result of extensive cooperation between EPA, industry, university, and SCS personnel. The guidance and assistance of Mr. Robert Landreth, Project Officer, Municipal Environmental Research Laboratory (MERL) of U.S. EPA, Cincinnati, Ohio, is gratefully acknowledged.

We wish to express our appreciation to our consultants on this project - Dr. Van Volk, Soil Science Department, Oregon State University, Corvallis, Oregon; and Dr. Albert Page, Soil and Environmental Sciences, University of California, Riverside, California - for their assistance in locating useful information and review of several sections of Volume 1. Assistance from the personnel of the case study sites is also sincerely appreciated.

SCS project participants were Mr. David E. Ross, Project Director; Mr. Larry K. Barker, Project Manager; Dr. Hang-Tan Phung, Soil Scientist; and Mr. David Bauer, Environmental Scientist. Ms. Jackie Wittenberg edited the draft report and checked the bibliography of the final version.

SECTION 1

INTRODUCTION

There is a definite need for information concerning the operational procedures and problems associated with land cultivation. Such information is best obtained by visiting operational sites, interviewing personnel, and observing procedures. Even with this input, inadequate knowledge of the impacts of land cultivation on soil and vegetation is readily available since most existing land cultivation sites have monitoring programs limited only to groundwater and surface water.

Significant effort in this project was devoted to field investigations; a total of ten sites were visited. Six of these sites were visited twice, with the interval between visits ranging from 2 to 9 mo. At each of the ten sites, local personnel were interviewed to obtain information concerning site and waste characteristics, operational procedures, and problems. In addition, soil and vegetation samples were collected at seven of the sites. Analysis of these samples provides an insight into the buildup and vegetative uptake of waste components.

Sections 2 and 3 of this volume discuss results of field investigations at ten land cultivation sites. These ten sites represent a variety of waste and site characteristics, climate, and waste application techniques. Four sites are presented in Section 2, each cultivating an industrial waste. Both soil and vegetative samples were collected and analyzed at these sites. Analytical results are presented along with brief narrative site descriptions.

Detailed reports on six case study sites are found in Section 3. Soil and vegetation samples were collected at three of these sites, with only interviews and observations performed at the other three. The report on the Michigan site is less detailed than that on the other five sites. Operating cost information was also collected from each site.

Other nonstandard disposal or waste utilization techniques for hazardous wastes are discussed in Section 4. This section reviews waste types utilized or considered for nonstandard disposal, as well as the disposal techniques being employed.

over

Cont'd

The location of most of the case study sites is given in only general terms, such as Rhode Island. Further, the companies involved as waste generators or disposers are not identified. Such anonymity protects proprietary information about processes and operations.

SECTION 2

FIELD STUDIES OF THE IMPACT OF LAND CULTIVATION ON SOILS AND VEGETATION

OVERVIEW

An important consideration in land cultivating an industrial waste is the determination of the effects of the waste on the soils and vegetation. Such a determination is particularly significant for hazardous wastes and for sites producing crops which may enter the food chain. Four sites which land cultivate hazardous wastes were visited, with soil and vegetation samples collected and analyzed. Three of these sites had crops growing.

Brief site reports for the four sites are presented in this section. Each report includes a description of the waste and the site, and a discussion of the analytical results. Waste and crops at the sites are:

- Arizona - waste sulfuric acid (subsurface injection) with alfalfa grown
- Eastern Pennsylvania - tannery buffing dust slurry on corn and clover fields
- Oklahoma - various refinery sludges on experimental plots, some of which were planted to wheat
- Texas - refinery sludges with no crops grown.

Wheat was grown only on an experimental basis at the Oklahoma site. There are no plans to produce wheat on the full scale land cultivation fields, and the small quantities already grown and harvested will not enter the food chain.

It appears that, with the application rates used at these sites, crops produced are fit for animal or human consumption. However, due to the limited scope of the sampling and analyses performed, such a conclusion can only be tentative. Further sampling is required to confirm this.

ARIZONA

Introduction

Waste sulfuric acid production is rapidly increasing due to the implementation of stringent air pollution regulations. Two of the major potential sources of such sulfuric acid, nonferrous smelting industries and coal-burning power plants, are found in several locations in the arid southwestern United States (1).

The potential value of sulfuric acid for improving the productivity of alkaline soils and irrigation water in arid regions has long been recognized. However, its actual use has not been extensive, partly because of limited supplies, handling difficulties, and inadequate application criteria. With the current surplus of sulfuric acid, agricultural use may offer a partial solution to disposal and management problems.

The objectives of this study were to:

- Investigate waste sulfuric acid production
- Review the agricultural uses of waste sulfuric acid
- Discuss analytical results of field samples
- Assess trace element accumulation in soils and plants, and other potential environmental problems associated with sulfuric acid application.

Sulfuric Acid Production

Currently, the exact amount of waste sulfuric acid produced in the United States is not known. The estimated figure is 4 million t (4.4 million tons) per year, primarily from nonferrous smelting plants and, to a lesser extent, from coal-burning power plants (2). If current air pollution regulations are fully implemented by these plants, the 4 million t/yr can be easily doubled. Although there is a large demand for acid by various industries, it can be met by about one-half of the total acid production.

Agricultural Uses

Considerable quantities of surplus acid can be employed beneficially for many agricultural uses, including: reclaiming sodium-affected calcareous soils, increasing the availability of phosphorus and various micronutrients, treating alkaline and ammoniated irrigation water, controlling certain weeds and soil-borne pathogens (1). Principles involved in these uses are reasonably well established; however, studies are required to determine effective techniques to implement the uses, especially the method of field application.

Sodic Soil Reclamation--

Approximately 10 million ha (25 million ac) of irrigated land in 17 western states is affected by sodium with varying levels of soluble salts (3). Excessive amounts of exchangeable sodium cause poor soil structure (thus restricting water penetration), high pH, and poor germination and plant growth (4, 5). Therefore, it is sometimes advantageous to remove excess sodium by field application of acid. This is accomplished by applying concentrated acid on soil surfaces under gravity flow by tractors or trucks equipped with sprinklers (6). After these surface applications of acid, there must be adequate leaching to remove soluble salts. When acid application rates are less than a few metric tons per hectare, the acid can be applied through leaching water or the first irrigation water. However, restoration of soils with very high sodium levels can be very expensive and time consuming.

The amount of acid required to permanently reclaim sodic soils depends on soil and water properties as well as on crop species. This amount ranges from 2 to 6 t/ha (1 to 3 tons/ac) for improving moderately sodium-affected soils, to 6 to 12 t/ha (3 to 5 tons/ac) for reclaiming severely sodium-affected soils (1). Based on the entire area of irrigated land affected by sodium with varying levels of soluble salts, and assuming a total one-time application rate of 5 t/ha (2 tons/ac), the total amounts of acid required for sodic soil reclamation are 2, 10, and 15 million t (2.2, 11, and 16.5 million tons) in Arizona, four southwestern states (Arizona, New Mexico, Utah, and Colorado), and California, respectively. Although these figures are crude estimates, the order of magnitude indicates the existence of sites that could receive a large portion of surplus acid.

Increased Nutrient Availability--

The high pH and lime content of calcareous soils in arid regions often limits solubility and availability of phosphorus and certain micronutrients (e.g., Fe, Mn, and Zn). As a result, deficiencies of these nutrients in various crops are commonly reported.

Elemental S and, to a limited extent, sulfuric acid have been studied as a means of correcting these deficiencies. In general, acidification of calcareous soils increases the solubility of the above elements (P, Fe, Mn, and Zn) originally present in soils and those applied as fertilizers (7, 8, 9, 10). Localized acidification by band or spot treatment generally produces better results than those produced by mixing acid thoroughly with soils or by applying acid continuously to irrigation waters at comparable total application rates (9).

Depending on method of application, soil cation exchange capacity, percent base saturation, and original pH, acidification requires an application rate of 560 kg/ha (500 lb/ac) to 6.7 t/ha (3 tons/ac) per growing season to increase crop yields (9, 11) (Palmer, personal communication).

Irrigation Water Treatment--

Irrigation water containing high levels of Na relative to Ca is known to cause adverse effects on soil physical conditions (e.g., water infiltration). High levels of bicarbonate in irrigation water accentuate the sodium hazard by precipitating Ca (12).

Sulfuric acid and other sulfur compounds (e.g., gypsum) have been used for reducing the Na-to-Ca ratio, thereby maintaining favorable soil physical conditions. Acid applied to irrigation water removes bicarbonate (as well as carbonate) and reduces Ca precipitation and Na accumulation in soils (12, 13). Acid applied to irrigation water also reduces the volatile loss of NH_3 in water and on soil surfaces (14). This appears to be related to the lowering of water and soil pH.

The amount of acid needed for reclaiming sodic soils with irrigation water treatment ranges from 50 to 200 ppm or 0.5 to 2 t/ha-m water (1). When surface irrigation systems contain concrete ditches or metal pipes, acid amounts are limited to about 90 percent of the equivalent amount of bicarbonate to avoid corrosion. No standard amount of acid has yet been established for sprinkler systems.

Weed and Pathogen Control--

Many weed species can be controlled by diluted sulfuric acid (2 to 10 percent by weight) at application rates of 25 to 100 kg acid per hectare (15, 16). By utilizing the differential tolerance, the quantity of weeds in small grains and onion fields has been controlled successfully. Dilute acid was formerly used extensively for weed control, but its use has declined because of the rapid development of organic herbicides, and corrosion and hazards associated with acid spray.

Sulfuric acid has been studied for controlling pathogens that are sensitive to acidity, such as Teras root rot and Helminthosporium turcium Pass (17).

Other Potential Uses--

In addition to the agricultural uses already mentioned, other potential uses of surplus acid include:

- Enhancing range grass establishment
- Reclaiming sodium-affected land or mine spoil banks

- Controlling dust and increasing grass production in alkaline dry lake beds

- Supplying sulfur fertilizer to agricultural soils

- Controlling soil crusting, algae, and aquatic plants.

Field Sampling

Field sampling of soils and alfalfa from plots that had received sulfuric acid applications was conducted at a ranch located south of Phoenix, Arizona.

Site Description--

The ranch has a total area of about 1,296 ha (3,200 ac), which is divided into 36 plots of various sizes.

The region has a dry climate; only 15 to 20 cm (6 to 8 in) of rainfall is received annually. Winters are mild, with a normal January low temperature of $2^{o}C$ ($35^{o}F$), while summers are hot, with a normal July high of $40^{o}C$ ($105^{o}F$). Humidity is generally low.

The soils are Antho sandy loam and Gilman loam, and are located on flood plains and alluvial fans. These soils are calcareous, well drained, and are used for most of the irrigated farming common to the area.

Acid Application--

Typically, soon after harvest of the cotton and alfalfa crops, the soil was plowed, loosened, and leveled. Waste-concentrated sulfuric acid was applied once through subsurface (0 to 7.6-cm) injection, using a special acid injection rig attached to a large tractor (Figure 1). Essential features of the rig consisted of a steel tank and knifing edges with injection pipes (Figure 2). Such a rig could reportedly inject acid at about 30 ha/day (74 ac/day). If needed, anhydrous ammonia or phosphoric acid could be simultaneously injected with the sulfuric acid.

The acid was commercially available at \$13.6/t (\$12.3/ton) plus \$15.4/t (\$14/ton) for freight. This amounts to \$29/t (\$26.3/ton). Acid was obtained from the mining companies in surrounding areas.

Sampled Plots--

Acid was injected into five plots in October 1976 at calculated rates of 448 to 560 kg/ha (400 to 500 lb/ac). Plots 25 and 34 (shown in Figure 3) were arbitrarily selected as the acid-treated and control plots for field sampling. Plot 25, with a total area of 20 ha (50 ac), received an application rate

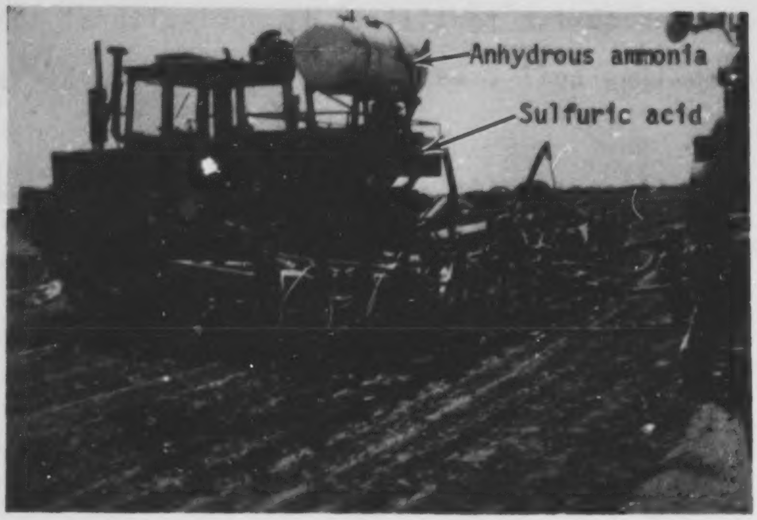

Anhydrous ammonia
Sulfuric acid

Figure 1 . Special acid injection rig attached to a large tractor.

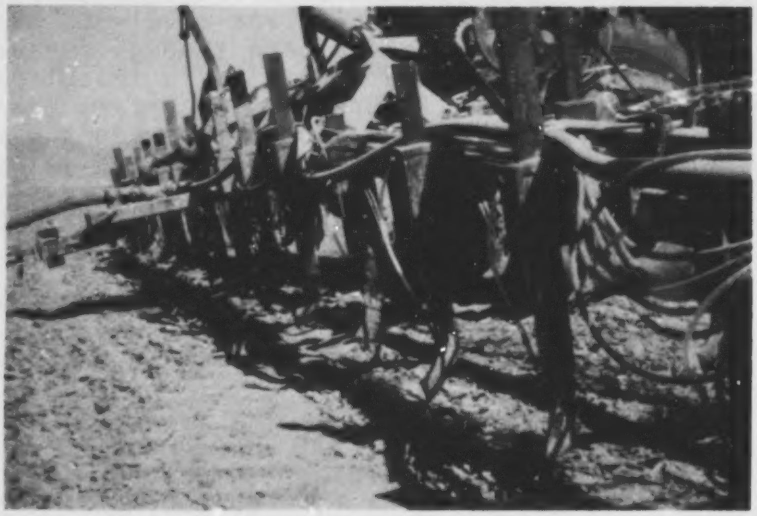
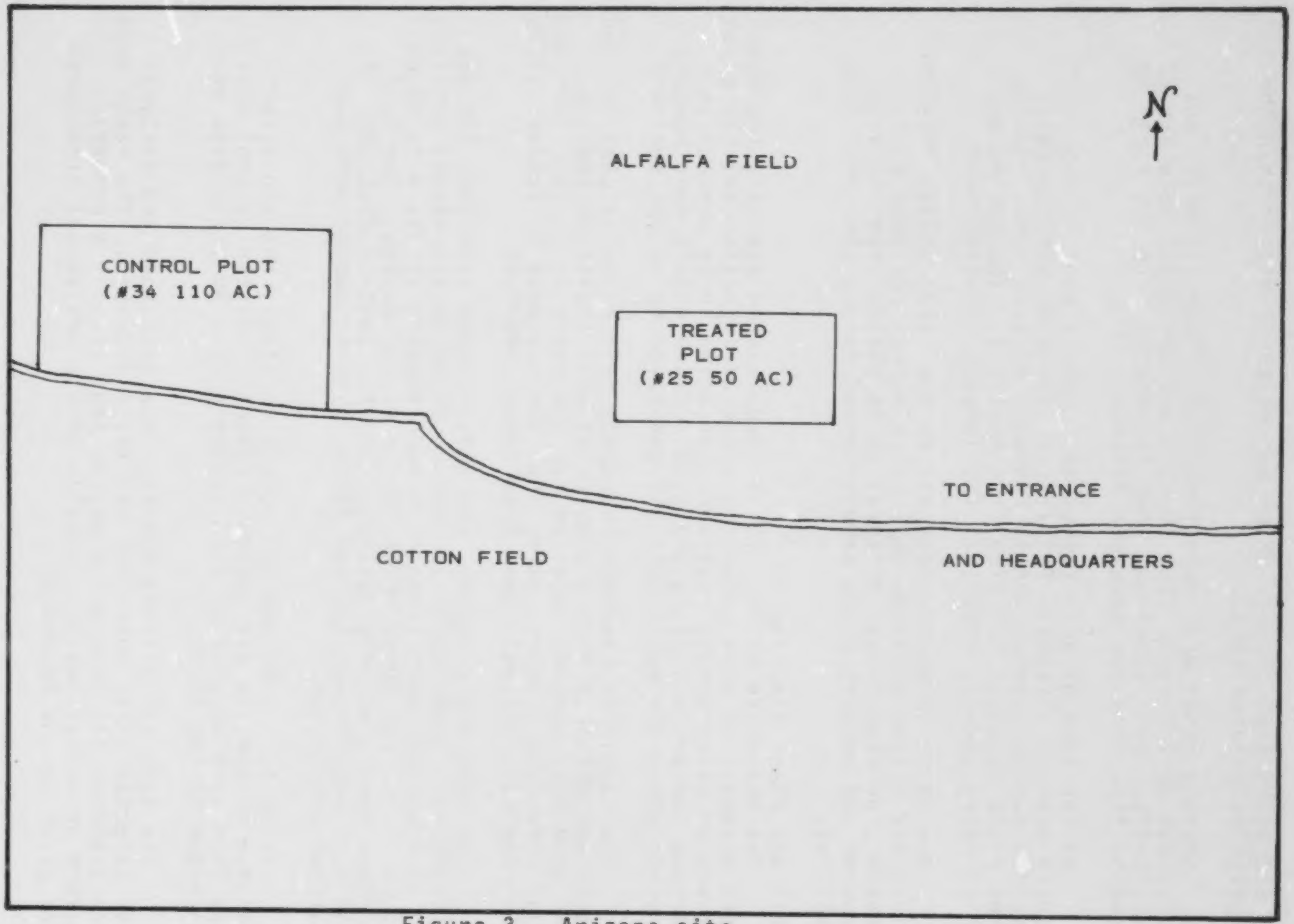


Figure 2 . Knifing edges with injection pipes.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(#25 50 AC)
TO ENTRANCE
COTTON FIELD
AND HEADQUARTERS

Figure 3. Arizona site.

of 618 kg/ha (552 lb/ac), which was slightly higher than the highest calculated rate.

Shortly after acid injection, fertilizer (18-46-0) was broadcast at 224 kg/ha (200 lb/ac), and the plots were seeded to alfalfa. Well water was then introduced into the plots by gravity flow from the concrete ditches.

At the time of acid injection, control plot 34 was in its fourth year of alfalfa. Fertilizer (18-46-0) was typically applied during seeding and in February of each year. Normal crop yield is about 3.4 t/ha (1.5 tons/ac). The second and third years usually result in the largest alfalfa yield.

Due to an unusual cold spell in May 1977, yields from the first and second cuttings were below normal for both plots. However, no significant differences in yields from the acid-treated and control plots were observed during the first four cuttings.

Soil and Plant Sampling--

The objective of this field study was to evaluate the downward movement of acid below the depth of injection and the plant uptake of heavy metals that were suspected to be present at various concentrations in the acid. Heavy metals were assumed present since the waste acid was generated by copper smelters.

The sample of concentrated waste sulfuric acid used for the ranch was obtained from a commercial acid injection company. The acid this company injected for the ranch in October 1976 may have come from a source other than the one used in October 1977. Nevertheless, all acid came from copper smelters.

For sampling purposes, the acid-treated plot (No. 25) was divided into three equal subplots. Prior to the second cutting, 10 soil borings were taken from each subplot at the 0 to 30 cm (0 to 12 in) and 30 to 60 cm (12 to 24 in) depths. Ten soil borings were similarly obtained from the control plot (No. 34). The soil samples at the same depth in each subplot were composited and bagged.

Prior to the second and fourth cuttings, the aboveground portion of alfalfa was randomly clipped from the control plot and from each subplot of the treated plot. No yield data were recorded in the field.

The soil and alfalfa samples were processed and analyzed for selected plant nutrients and trace elements. The waste acid was analyzed for some trace metals that present a potential hazard to animal health. Details of the analytical procedures are given in the Appendix.

Assessment of Trace Element Accumulation in Soil and Plant

Acid Analyses--

Concentrations of the trace elements and heavy metals analyzed in the acid sample are presented in Table 1. This acid contained relatively high levels of iron, which would be beneficial to the alfalfa crop since most calcareous soils are deficient in this micronutrient (1). Since none of the elements were present in excessively high concentrations and since the soils in this area are highly calcareous and strongly alkaline, the availability of these elements (except for selenium) for plant uptake would be very low.

TABLE 1. TRACE ELEMENT CONCENTRATIONS IN WASTE SULFURIC ACID*

Element	Concentration µg/ml
Fe	886
Mn	5.47
Cu	1.12
Se	0.045
Ni	15
Zn	5.3
Pb	0.27
Cd	0.25
Co	0.13

*Acid sample was obtained on October 3, 1977.

Soil Analyses--

Surface (0 to 30 cm) and subsurface (30 to 60 cm) soils were collected from the control and the acid-treated plots and analyzed for various elemental constituents. The results are given in Table 2.

Since the acid application rate (618 kg/ha) is considered to be very low, effects of the acid treatment on the chemical properties of the soil were not apparent. Soil pH, for example, was not changed as a result of acid application.

Significant amounts of sodium had leached below the surface 30 cm (12 in) depth. The sodium adsorption ratios (SAR) and electrical conductivities indicate that the soil is suitable only for crops that are relatively tolerant to high sodium and salinity levels.

TABLE 2. CHEMICAL ANALYSIS OF SOILS TAKEN AT TWO DEPTHS FROM ARIZONA SITE

	Control		Acid treated*	
Parameter	0-30 cm	30-60 cm	0-30 cm	30-60 cm
pH	8.0	8.0	8.1	8.1
SAR†	7.58	8.32	7.26	11.36
EC, mmohs/cm	4.2	4.1	3.2	4.62
Total N, μg/g	851	360	540	337
	-------- 0.1N HCl-extractable, μg/g ---------			
Ortho-P	110	126	84.4	67.8
SO_4	375	310	337	346
Se	<0.003	<0.003	<0.003	<0.003
Mo	0.21	0.16	0.26	0.38
Fe	3.5	3.8	2.2	1.6
Mn	16.8	11.4	12.8	8.5
Cu	0.43	0.40	0.34	0.23
Ni	3.6	0.4	1.1	2.0
Pb	<0.1	0.5	0.3	0.1
Cr	0.33	0.33	0.22	0.25
Cd	0.22	0.04	0.03	0.06
Co	1.55	1.17	1.36	1.32
Zn	1.3	0.95	0.61	0.23
	----------- Water-soluble#, μg/ml -----------			
Cl	973	1,098	677	1,042
Na	580	620	433	698
K	25	19	28	25
Ca	296	280	176	160
Mg	90	86	57	87
B	0.55	0.26	0.41	0.56

*Average of three samples.

†Sodium adsorption ratio (SAR) is an index of sodium hazard.

#Measured in water-saturation extracts.

When a soil is acidified by sulfuric acid, it is expected that the availability* of orthophosphate and most trace elements will be increased. However, this was not observed on the acid-amended soil due to the low acid application rate and soil variability. Generally, no significant accumulation or leaching of the trace elements and metals below the depth of acid incorporation was noted. The data suggest that the acid application did not adversely affect the soil chemical properties.

Plant Analyses--

There were no significant differences in the alfalfa stand between the control and treated plots during the second or fourth cuttings. However, comparison of the elemental composition of alfalfa grown in the control and treated plots may not be valid, since the alfalfa in the control plot was in its fourth season, while the alfalfa in the treated plot was only in its first season. The alfalfa in the control plot was slightly damaged by insects prior to the fourth cutting, creating sporadic empty spots in the field. Although no yield data were recorded, it was noted that the crop stand was generally better in the fourth cutting than in the second.

Results of the plant analyses are presented in Table 3. Concentrations of nitrogen, phosphorus, sodium, calcium, magnesium, sulfur, copper, lead, and cobalt were considerably higher in the fourth than they were in the second cutting. These increases may be attributed, in part, to a better alfalfa crop in the fourth cutting. The increase in nitrogen content is of particular significance to the farmers, since higher nigrogen (protein) means better quality.

There were no consistent differences in the concentrations of various elements in alfalfa between the second and fourth cuttings due to acid treatment. For example, the boron concentrations were 7.13 and 9.08 μg/g from the control and treated plots in the second cutting; they were 13.12 and 8.17 μg/g in the fourth cutting. Part of this discrepancy was probably due to the nature of soil variation and uneven application or distribution of the acid in soil.

Iron concentrations in alfalfa were significantly increased as a result of acid application. These increases, however, were not reflected in the 0.1N HCl-extractable iron levels in soil. Plant uptake of other trace elements was not increased by the acid treatment. Again, this may be attributed to the low acid application rate and high buffer capacity of the soil.

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*Concentrations of various elements extracted by 0.1N HCl are presumably indicative of their availability for plant uptake and/or potential for movement in soil.

TABLE 3. CHEMICAL ANALYSIS OF ALFALFA AT TWO CUTTINGS FROM ARIZONA SITE

	Second cutting		Fourth cutting	
Element	Control	Treated*	Control	Treated*
	- - - - - % - - - - -		- - - - - - % - - - - - - -	
N	2.91	2.66	3.47	3.72
P	0.14	0.15	0.22	0.25
K	2.13	2.28	1.78	1.21
Na	0.10	0.08	0.53	0.47
Ca	0.64	0.73	1.48	1.53
Mg	0.18	0.16	0.34	0.32
S	0.19	0.19	0.30	0.32
	- - - - µg/g - - - -		- - - - µg/g - - - - -	
B	7.13	9.08	13.12	8.17
Se	0.31	0.16	0.03	0.05
Mo	4.14	4.08	3.67	4.39
Fe	60	129	67	109
Mn	26.7	24.3	32.1	29.0
Cu	7.9	6.8	10.6	11.2
Ni	9.0	2.3	8.8	4.0
Pb	2.0	0.83	<0.83	4.52
Cr	9.58	4.72	1.25	1.53
Cd	0.03	0.03	0.11	0.24
Co	0.56	0.56	1.45	1.28
Zn	29.5	39.4	35.3	35.6

*Average of three samples.

Conclusions

Based on the preliminary chemical analyses of waste acid, soil and alfalfa samples, the following conclusions can be drawn:

- Since the acid application rate was low, the soil pH and availability of nutrients and heavy metals were not significantly altered.
- No significant accumulation or movement of heavy metals away from the zone of acid incorporation occurred in the acid-treated soil.
- Concentrations of nitrogen, phosphorus, sulfur, magnesium, calcium, and sodium were significantly higher in alfalfa from the fourth cutting than from the second cutting.
- Except for iron, concentrations of various elements analyzed in alfalfa were not significantly altered by the acid treatment.

EASTERN PENNSYLVANIA

Introduction

The leather tanning and finishing industry generates a waste that is considered to be potentially hazardous. This waste consists of chrome trimmings and shavings, chrome fleshings, unfinished chrome leather trim, buffing dust, finishing residues, finished leather trim, and wastewater treatment residues (18). This waste generally has high concentrations of chromium, lead, copper, and zinc.

Present disposal techniques for tannery waste include open dumping; landfilling (sanitary and "secure" landfills); disposal in lagoons, trenches, pits, and ponds; discharge to municipal sewage treatment; and agricultural spreading. Land cultivation of tannery waste is not widely practiced, probably because of the high concentrations of heavy metals (especially chromium) in the waste stream.

The site selected for this field study has a long history of land cultivation of tannery buffing dust solids and slurries. The objective of this site survey is to determine the effects of waste application on metal accumulation in soil and on uptake by crops.

Site Description

The land cultivation site, which is operated by the farm owner, is located in a rural area in eastern Pennsylvania. The total area of the site is about 12 ha (30 ac).

The site layout is presented in Figure 4. Topography of the site ranges from relatively flat (less than 1 percent slope) to gently rolling (about 5 percent slope). A surface stream runs along the western boundary of the site, and drainage is predominantly towards the south and west.

Since land cultivation at this site is oriented toward waste utilization, various crops are grown, such as wheat, hay (including clover), and corn. Approximately a dozen fruit trees (including pear, apple, and chestnut) grow on the property. Fruit from these trees is consumed by the owner's family and is marketed at a roadside stand for consumption by local residents. The corn grown, as well as some of the hay, is used for animal feed. Some of the hay is also sold to mushroom growers in the area for use as mulch. Wheat is not a common crop on the site, but when grown it is sold to local brokers.

Soil in the area is primarily a Chester channery silt loam, well drained, and moderately eroded. It contains many coarse fragments, which increase at lower depths (>99 cm). Surface runoff is slow to very rapid, and permeability throughout the profile is moderate. Slope is the major limitation to use of this soil for farming.

Depth to groundwater at this site is not known. Several nearby residents have private wells to provide their household water.

The area has a fairly moderate, humid, continental climate. The average monthly temperatures normally range from slightly more than -1°C (30°F) in January to 25°C (77°F) in July. An increase of about 5°C (10°F) takes place each month from March through June, and a decrease of about 5°C (10°F) takes place each month from October through December. Annual precipitation totals about 104 cm (41 in). Rainfall evenly distributes throughout the year with July and February being the wettest and driest months, respectively.

Waste Source and Characteristics

The waste cultivated at this site is generated by finishing operations at a nearby tannery. One of the finishing operations normally conducted in a chrome leather tannery is buffing. Buffing dust is produced when the dried and trimmed leather is mechanically sanded to remove surface imperfections or to improve the nap of the flesh side. In the tannery, a wet

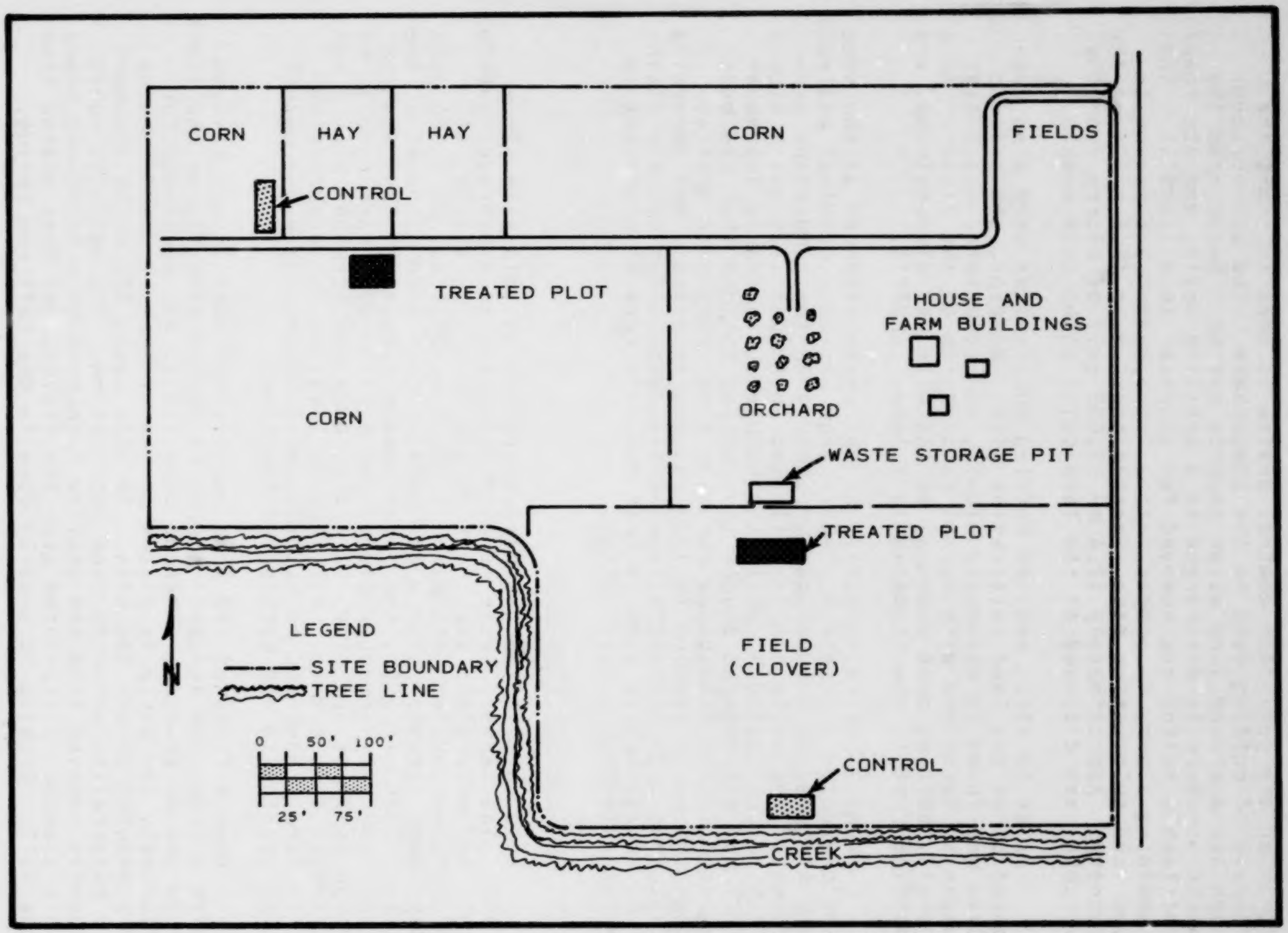

CORN
HAY
HAY
CORN
FIELDS
CONTROL
TREATED PLOT
HOUSE AND
FARM BUILDINGS
ORCHARD
CORN
WASTE STORAGE PIT
TREATED PLOT
LEGEND
SITE BOUNDARY
TREE LINE
N
FIELD
(CLOVER)
0
50'
100'
25'
75'
CONTROL
CREEK

Figure 4. Eastern Pennsylvania land cultivation site.

scrubber air pollution control device is used to limit the release of buffing dust to the atmosphere. The wet scrubber used has a closed-loop water recycle system. Water from the waste scrubber is discharged to a settling basin, and the readily settleable solids are removed for disposal to a landfill. The remaining slurry is pumped into a "Honeywagon" and hauled to the land cultivation site, located about 4 km (2.5 mi) from the tannery. Approximately 11.4 m^3 (3,000 gal) of slurry from the scrubber are disposed at the land cultivation site weekly.

Prior to 1973, settled buffing dust solids were also disposed of at the land cultivation site. However, the buffing dust was found to decompose slowly, so accumulated quantities began to interfere with normal cultivation of the fields. As a result, buffing dust disposal at the site was discontinued, and buffing dust is now disposed in a local landfill.

Chemical characteristics of the waste disposed at the site are presented in Table 4. (Data from previous chemical analysis are included as a supplement, rather than for comparison purposes.) The waste sample collected in August 1975 was a slurry (2.5 percent solids), while the sample collected in September 1977 was a dewatered sludge (90 percent solids) that had been exposed to the atmosphere for some time. The data indicate that the waste sampled in 1977 was highly organic and generally contained high concentrations of nitrogen, chromium, and titanium. Heavy metals such as lead and zinc were also present in relatively high concentrations.

Land Cultivation Practices

Land cultivation has been practiced at this site since 1961. The tannery waste is used primarily as a nitrogen supplement and an organic amendment to the soil. Initially, all process wastewater (estimated at 3.78×10^4 l/day or 1,000 gal/day) and scrubber slurry and buffing dust were disposed at the site. Then, in 1967, the local sewage treatment plant went on line, and only scrubber slurry and buffing dust continued to be disposed of at the site. In 1972, only the scrubber slurry was disposed at the site. All land cultivation has occurred on this farm. However, no records exist concerning waste quantities applied to any portion of the farm.

When a field at the land cultivation site is not covered with a crop, the scrubber slurry is spread directly on the field from the Honeywagon. When no open fields are available for disposal, the waste is placed in one of several small lagoons distributed around the site. In this case, the waste dewaters by evaporation prior to land application. The waste is subsequently removed from the shallow lagoons with a front-end scoop on a tractor, distributed over the fields, and then disked into the soil. Disking is usually done in the fall and spring.

TABLE 4. ELEMENTAL COMPOSITION OF THE TANNERY WASTE AT TWO SAMPLING DATES*

PENNSYLVANIA SITE

Element	Sampling Date August 1975†	 September 1977#
	- - - - - - - - - %	- - - - - - - - - -
N	--	6.75
Organic C	--	84.8
Al	0.80	--
Si	0.41	--
Ba	0.63	--
Cr	4.76	2.25
Ti	1.60	--
Fe	0.31	--
	- - - - - - - - - μg/g	- - - - - - - - -
Ca	530	--
Cu	13	53.1
Cd	--	2.12
Co	--	1.41
Ni	--	5.0
Pb	180	133
Mn	51	13.5
Zn	700	159
Se	--	0.056
S	--	983
Sr	82	--

* Concentrations expressed on dry weight basis.

† Unpublished data, SCS Engineers. Results are from spectrographic analyses of a grab sample of the buffing dust scrubber slurry.

# A grab sample of the dewatered sludge taken from the field.

Since the principal purpose of the land cultivation site is the production of agricultural crops (wheat, clover, and corn), waste disposal operations must be coordinated with planting and harvesting schedules.

No historical records have been maintained on the quantity of buffing dust and scrubber wastes that have been disposed of at the site, or on the exact location of disposal.

No permit is required by the State Department of Environmental Resources (DER) for land cultivation at the site. This is because the site owner maintains that the waste is utilized for its irrigation as well as nutrient and soil conditioning benefits and not primarily for disposal. The DER concurs and therefore has decided that a waste disposal permit is not necessary. Thus, no monitoring of the site is conducted. However, environmental factors are taken into consideration in the placement of the waste on the site. Care is exercised to prevent placement of wastes on steep slopes or within 32 m (100 ft) of surface streams.

Field Sampling and Chemical Analyses

Field Sampling--

Soil and vegetation sampling at the site was performed in September 1977. Ten surface (0 to 15 cm) soil samples were randomly taken from each of the waste-treated corn and clover fields. Since the soil immediately below the 0- to 15-cm depth was mixed with gravels, no sample was taken at the 15- to 30-cm (6- to 12-in) depth. For comparison, 10 soil samples were taken from the same depth at the control field where similar crops were growing but no sludge had been applied. Sampling locations are shown in Figure 4.

Vegetative samples were taken from corn kernels and the aboveground portion of clover from the control and waste-amended fields. One control composite and three treated composites were made from each crop. At the time of sampling, no differences in visual appearance (color, stand, and estimated yields) were observed.

Chemical Analyses--

Soil and plant composite samples were processed and analyzed for selected plant nutrients, trace elements, and heavy metals, according to the procedures given in the Appendix.

Soil analyses--Results of the chemical analysis of the surface (0 to 15 cm) soil from the clover and corn fields are given in Table 5. The EC and SAR values show that soil incorporation of the waste slurry or dewatered solids from the scrubber did not result in the buildup of soluble salts and sodium hazards. The impact of waste application on the chemical

TABLE 5 . CHEMICAL ANALYSIS OF SURFACE SOILS FROM THE CONTROL AND WASTE-TREATED CLOVER AND CORN FIELDS

PENNSYLVANIA SITE

Parameter	Clover Field		Corn Field	
	Control	Treated	Control	Treated
pH	6.4	6.3	5.3	5.9
EC, mmhos/cm	0.37	0.35	0.30	0.40
Total N, %	0.16	0.28	0.15	0.19
- - - - - 0.1N HCl-Extractable, μg/g - - - - -				
Ortho-P	1.7	6.5	4.4	13.5
SO_4	22	7	2.5	2.5
Fe	22.7	24.0	22.0	17.0
Mn	131	180	103	154
Cu	5.81	4.31	4.12	5.44
Ni	1.83	2.33	<0.07	1.00
Pb	3.0	6.0	4.83	6.67
Cr	1.0	3.2	0.6	1.1
Cd	0.08	0.17	0.10	0.12
Co	1.22	1.44	0.97	1.06
Zn	12.3	12.5	9.8	12.3
- - - - - Water-Soluble*, μg/ml - - - - - -				
B	<0.2	<0.2	<0.2	<0.2
Na	2.9	2.6	3.2	2.4
K	4.1	7.2	2.3	4.2
Ca	55	52	47	45
Mg	12.3	14.3	4.0	12.9
Cl	37	15	34	30
SAR	0.09	0.08	0.12	0.08

* Measured in the water saturation extracts.

properties of soils is different for the clover and the corn fields. However, there are increased concentrations of HCl-extractable orthophosphate, manganese, nickel, lead, chromium, and total nitrogen, and water-soluble potassium in the soils as a result of waste application.

None of the heavy metals analyzed showed excessively high concentrations in the HCl extracts. For example, a high chromium concentration (2.25 percent) was present in the waste; however, its concentrations in the treated surface soils were only 3.2 and 1.1 µg/g, respectively, from the clover and corn fields. The data suggest that either the application rate, which is unknown, was low or that the heavy metals were present in forms of which very little can be extracted by 0.1N HCl. Thus, the levels of heavy metals measured in the HCl extracts may not be indicative of the total concentrations in the soil. Based on the relatively low pH of the surface soil, some heavy metals (e.g., Zn, Ni, Cu, Cr, etc.) would be more available to plants than would normally be expected.

Plant analyses--Results of the chemical analyses of corn grain and clover tissue are presented in Table 6. Concentrations of nitrogen and potassium were increased, particularly in clover. These increases suggest that the tannery waste cultivated at this site may be an important source of nitrogen and potassium for clover. The nitrogen content (6.75 percent) of the waste is a good indicator of this nutrient value.

Waste application resulted in significant increases in lead and chromium concentrations in the clover tissue, and slight increases in zinc concentrations. These findings do not agree with Allaway (19), who found that chromium addition to soil generally caused only small changes in tissue chromium concentrations. The elevated tissue concentration of chromium may be beneficial to animals consuming the hay since chromium is essential for normal glucose metabolism (20). However, this concentration (77.1 µg/g) may also have cuased phytotoxicity in clover.

Elemental concentrations were generally lower in the corn grain than in the clover forage (Table 6). This suggests that heavy metals probably accumulated in the roots and forage; they were not translocated to the grain. The project scope did not allow for sampling and analysis of plant roots or forage. Overall, the impact of waste application on the elemental composition of corn grain appears to be insignificant.

Summary

Land cultivation at this site has been practiced since 1961. The waste is primarily a slurry from the scrubber of a tannery

TABLE 6 . CHEMICAL ANALYSES OF CLOVER AND CORN FROM THE CONTROL AND TREATED PLOTS

PENNSYLVANIA SITE

	Clover		Corn Kernel	
Element	Control	Treated*	Control	Treated*
	- - - - - - - - - - - - - %	- - - - - - - - - - - - -		
N	1.79	2.03	1.23	1.41
P	0.34	0.34	0.22	0.30
K	0.36	0.70	0.25	0.28
Ca	1.48	1.36	0.01	0.01
Mg	0.28	0.25	0.07	0.09
S	0.14	0.16	0.08	0.07
	- - - - - - - - - - - µg/g	- - - - - - - - - - - - -		
Na	315	282	16.2	16.4
B	7.88	5.71	--	--
Se	<0.016	0.05	--	--
Mo	5.06	2.38	--	--
Fe	712	464	97.3	81.8
Mn	120	119	6.43	7.04
Cu	12.27	12.24	2.23	1.86
Ni	28.75	10.52	8.60	8.98
Pb	3.12	7.18	2.56	2.34
Cr	32.2	77.1	5.9	4.9
Cd	0.09	0.20	0.04	0.04
Co	1.56	0.52	0.33	0.30
Zn	63.75	72.82	32.79	29.88

* Average of three samples

finishing plant, which is used as a nutrient source and an organic amendment.

Surface soil and vegetation (corn and clover) were sampled and analyzed for plant nutrients as well as various trace elements and heavy metals. Waste application increased the total nitrogen, water-soluble potassium, and HCl-extractable nickel, lead, and chromium in the soil. Tissue concentrations of nitrogen, potassium, zinc, lead, and chromium in clover were significantly higher in the waste-treated plot than in the control plot. However, the nutrient level and the heavy metal concentration in the corn grain were not affected appreciably by waste treatment.

The data suggest that the tannery waste disposed at this site may be a good source of nitrogen for crops. Also, the high chromium levels in the hay may be considered as a supplement for animals consuming the forage.

OKLAHOMA

Introduction

As part of its land cultivation program, a major oil company initiated a field study of oily waste land farming. The purpose of this study was to evaluate the cost effectiveness and environmental impacts of land farming, including heavy metal accumulation in soil and oil degradation rates. Also evaluated were the effects of nitrogen application and crops on oil degradation.

Although other petroleum refineries are practicing land cultivation, the work at this site was unique in its detailed experimental impacts, including potential heavy metal uptake by an agronomic crop grown on the oil-treated soil.

In this report, the various disposal methods for refinery wastes are reviewed, and the preliminary results from the field study are discussed.

Refinery Waste Disposal

Based on the findings from site visits to 16 petroleum refineries in the United States, Lofy (21) listed 17 waste streams requiring disposal and discussed nine treatment and/or disposal technologies that were used by the refineries. According to Lofy, these waste streams are hazardous because of the presence of one or more contaminants at toxic levels. The contaminants in many cases are a combination of oil and one or more heavy metals.

Some of the various technologies for treatment and/or disposal of these potentially hazardous waste streams are as follows:

- Landfilling
- Landspreading
- Lagoons, ponds, sumps, and open pits
- Incineration
- Deep well disposal.

Landfilling--

Landfilling is presently the most widely used method for disposing of all types of petroleum refinery wastes. The environmental adequacy of this method is contingent upon the types and characteristics of the wastes, as well as upon systems of operation and specific site geologic and climatologic conditions. Many of the landfill sites that receive refinery wastes would probably be designated as Class II-2 (California definition).

Landspreading--

Landspreading, or land cultivation, is a relatively inexpensive method of disposal for petroleum refinery wastes, which is being used by a growing number of refineries. Lofy indicated that the rate of degradation and disappearance of the oily wastes requires between 1 and 6 mo, depending upon the thickness of the sludge deposit, oil content in soil, amount of fertilizer (nitrogen and phosphorus) used, climate, and frequency of tilling. Not all refinery wastes are suitable for landspreading (22); however, waste biosludge, tank bottoms, and API separator sludge can be disposed of by this method. The major environmental concern associated with landspreading of refinery wastes is the long-term implications of trace metal accumulation in soil with repeated application.

Lagoons, Ponds, Sumps, and Open Pits--

Lagoons, ponds, sumps, and open pits have been used for many decades by the petroleum industry for the disposal of liquid and semi-solid waste. Because of their simplicity and ease of construction, earthen or lined lagoons are used by many of the newer refineries as primary or secondary sedimentation chambers; aeration basins; emergency oil spill retention basins; and as oxidation, storm runoff, evaporation, or thickening ponds. There is considerable potential for significant contamination of underlying water aquifers from inadequately lined lagoons, because of improper lagoon location, and inadequate safeguards.

Incineration--

Refinery wastes that are sometimes incinerated include spent caustic solutions, API separator bottoms, DAF float, waste biosludge, and slop oil emulsion solids. Among the disadvantages of incineration are high capital cost, high recurring annual operation and maintenance costs, and expensive air emission control devices. Incineration can result in the emission of volatilized metals such as beryllium, nickel, and vanadium, along with fine particulate matter.

Deep Well Disposal--

Refinery wastes that are disposed of by deep well injection include sulfidic solutions generated by caustic washing of crude cracking and hydrotreating streams, sour water from hydrotreating units, brines from desalter operations, and other weak solutions from crude processing and preheating. The capital and operating costs for deep well disposal can be considerable. The environmental impacts of this method are not yet fully known.

Field Study

Prior to full-scale land cultivation of refinery wastes, the oil company initiated a long-term field study to assess the environmental impacts of soil incorporation of these wastes under local conditions. The objectives of the study were to:

- Determine the fate of oil, metals, and salts in the waste added to soil

- Measure the composition of surface runoff (if it were allowed to occur)

- Determine if plants grown on oil-treated soil would take up excessive amounts of heavy metals or salts.

This study was begun in April 1976 and will last for several years.

Site Description--

The site used for the study is a landfarm and experimental plots, which are adjacent to a tank farm owned by the company.

The area has a temperate, subhumid climate. Summer is hot and wet with dry spells. Cold Canadian air often invades the area during the winter, leaving an average of 20.1 cm (7.9 in) of snow. Annual precipitation is 71.5 cm (32.1 in) scattered throughout the year.

The soil at the site is primarily a Vanoss silt loam that is moderately well drained, friable, and slightly acid. This soil is well suited to farming.

Field Experimental Procedures--

The field experiment - which was a completely randomized design with three replications - was conducted in an area next to the landfarm (Figure 5). The area had 9 control and 18 oil-treated plots, each measuring measured 6.1 m x 22.9 m (20 ft x 75 ft).

After the area was cleared and all plots were laid out, ammonium nitrate and triple superphosphate were broadcast to all plots at rates of 112 kg N/ha (100 lb N/ac) and 19.6 kg P/ha (17.5 lb P/ac). In addition, half of the 18 treated plots received another 112 kg N/ha of ammonium nitrate.

In May 1976, an oil sludge was applied at a rate of approximately 5 cm (2 in) thick to the 18 treated plots (Figure 6). This application was close to 5 percent oil on soil basis. The sludge was from mixed sources - primarily API bottom material - and was composed of 18 percent oil, 54 percent water, and 28 percent solids (biosludge and sand). The company had determined the chemical composition of the sludge, which showed unusually high concentrations of various metals.

After application, the sludge was allowed to dry. It was then rototilled in the surface 15 to 20 cm (6 to 8 in) of soil. Six subsequent tillings were done prior to the planting of winter wheat (Tam 101), which was seeded to three control and six oil-treated plots in October 1976. The purposes of growing wheat on the test plots were to determine the effect of wheat growth on oil decomposition rate and the effect of oily waste on wheat growth and heavy metal uptake. Winter wheat was harvested in July 1977. Recorded yields were as follows:

Treatment (N applied)	Grain Yield Index
• Control (112 kg N/ha)	1.000
• Oily Waste Treated (112 kg N/ha)	0.985
• Oily Waste Treated (224 kg N/ha)	1.290

There were average yields from the three replications. It appeared that grain yield was not affected by the application of oily waste at the same nitrogen level, but was slightly increased as a result of additional nitrogen application. However, the overall effect of landfarming of oily waste on wheat growth should be evaluated, not only by the yield data but by the chemical composition of leaf and grain samples.

The company also sampled soil from the control plots bimonthly and analyzed for oil components, metals, and nutrients.

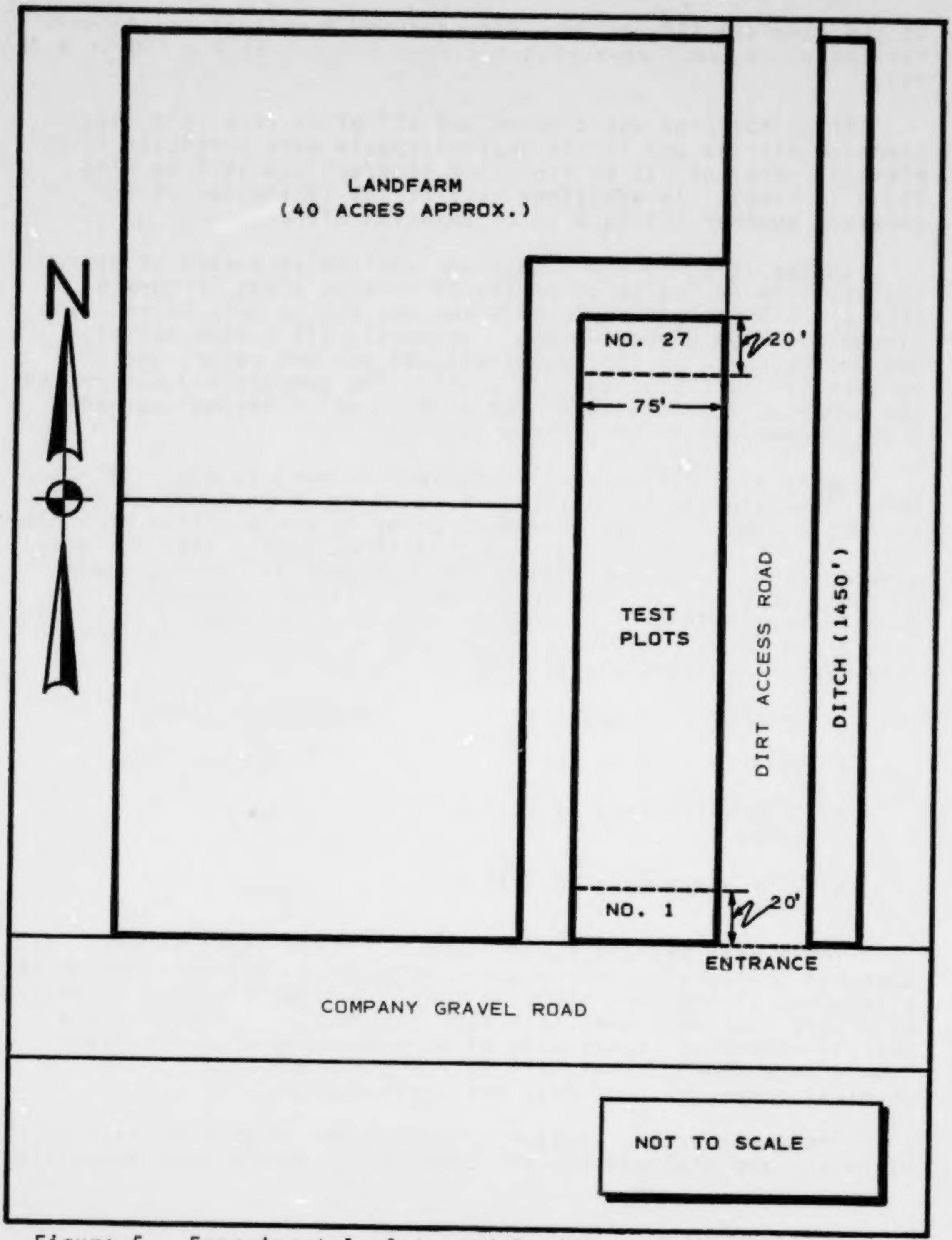

LANDFARM
(40 ACRES APPROX.)
N
NO. 27
20'
75'
TEST
PLOTS
DIRT ACCESS ROAD
DITCH (1450')
NO. 1
20'
ENTRANCE
COMPANY GRAVEL ROAD
NOT TO SCALE

Figure 5. Experimental plots and landfarm at Oklahoma site.

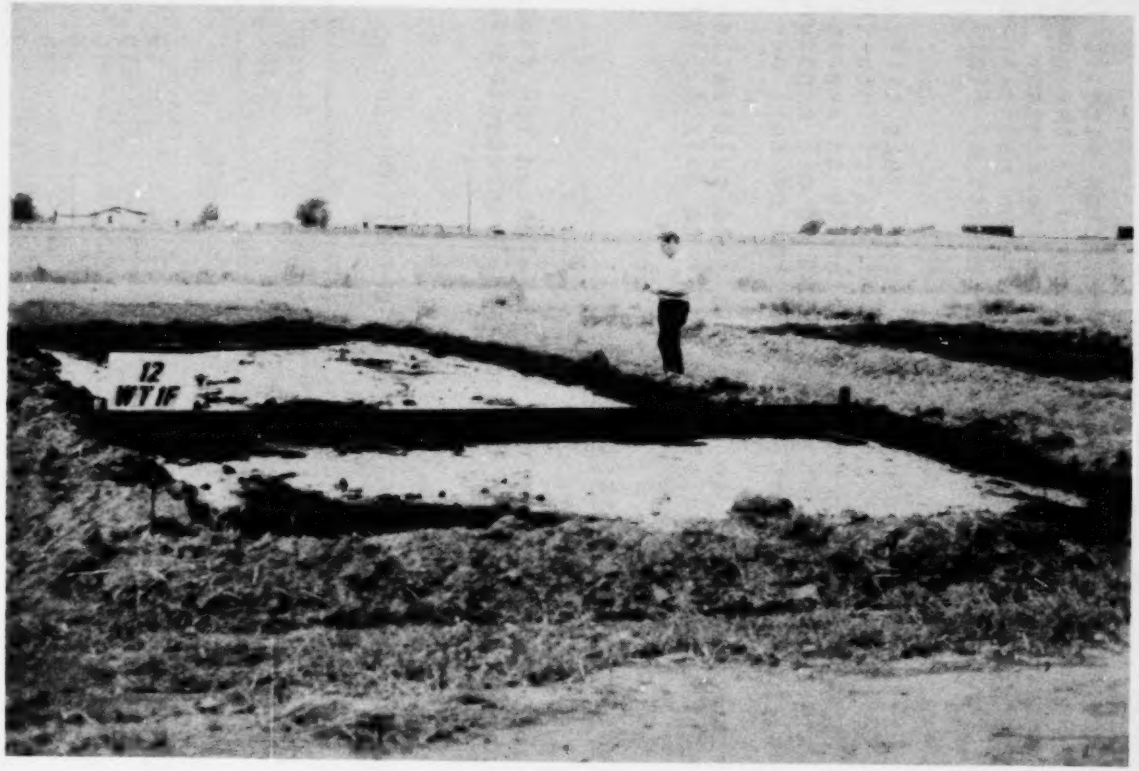


Figure 6. One of the experimental oil-treated plots at Oklahoma site.

Land Cultivation Practices

The company practiced land cultivation on a limited scale from 1975 to the summer of 1977, after which full-scale operations began. Prior to the initiation of land cultivation, oily waste was disposed of by road spreading and landfill or burial.

The current 16-ha (40-ac) land cultivation site is located in the tank farm, which is owned and operated by the company. The Research and Development Department of the company recommended that the optimum sludge loading rate be maintained at 5 percent oil (on soil basis), based on results of field experimentation.

Earlier studies by Cresswell (22) showed that tilling of refinery wastes (4 to 10 percent oil, soil basis) into the upper 15 to 20 cm (6 to 8 in) of topsoil resulted in an average oil degradation rate of 40 percent after 28 mo of oil exposure. This is equivalent to 8.5 g oil per kilogram of soil per year.

No permit was required to operate a land cultivation site in Oklahoma if the operation started prior to July 1, 1977, as was the case with this site.

SCS Field Sampling and Chemical Analyses

Field Sampling--

Pertinent information on the plots selected for field sampling was furnished by the company and is presented in Table 7.

TABLE 7. FIELD PLOTS SELECTED FOR SAMPLING - OKLAHOMA SITE

Plot No.	Oil in Soil	Nitrogen Applied	Phosphorus Applied
	%	----- kg/ha	-----
2	0	112	19.6
16	0	112	19.6
26	0	112	19.6
1	3.67	112	19.6
21	3.73	224	19.6
27	3.65	112	19.6

On July 26, 1977, soil samples were taken from the 0 to 30 cm (0 to 12 in) and 30 to 60 cm (12 to 24 in) depths from the control and oil-treated plots. For both depths at each plot, a total of 10 borings were taken, composited, and bagged.

The company supplied grain samples from the plots listed in Table 7. Ten grams of wheat taken from each of three control plots (Nos. 2, 16, and 26) were composited as one sample. No composite was made for grain samples from the treated plots.

Chemical Analyses--

Soil and plant samples were processed and analyzed for selected plant nutrients, trace elements, and heavy metals, according to the procedures given in the Appendix. The results are presented in Tables 8 and 9.

Soil analyses--Application of oily sludge resulted in increases in pH, levels of soluble salts (EC), and 0.1N HCl-extractable sulfate and metals (except for molybdenum) in the surface soil (Table 8). The data also suggest that sulfate had leached below the surface soil. No significant movement of heavy metals below the zone of oil incorporation was noted.

Oily waste addition significantly increased concentrations of water-soluble Na, Ca, and Mg in the surface soil (Table 8), and there was significant movement of these cations below the plow layer. Also increased was the sodium adsorption ratio (SAR), an indication of sodium hazard to growing crops. However, the SAR values were low and would not pose any sodium hazard to plant or soil.

Plant analyses--Results of plant analyses are presented in Table 9. Data from the individual treated plots are given together with averages. Note that plot No. 21 received 224 kg N/ha (200 lb N/ac), whereas all the control plots as well as plot Nos. 1 and 27 received only 112 kg N/ha (100 lb N/ac). Application of oily waste resulted in significant reduction in nitrogen uptake by wheat. This was due in part to the microbial immobilization of inorganic nitrogen when the carbonaceous oily waste was incorporated into the soil. Doubling the rate of nitrogen fertilizer did not affect concentrations of nitrogen or other elements analyzed in wheat grain from the treated plots.

Oil treatment increased the concentrations of B, Mo, Mn, Cu, Ni, Pb, Cr, Al, and Zn in the wheat grain. (There were not sufficient data to determine if the increases were statistically significant.) These concentrations, in part, are reflected in the soil analyses. The levels of these elements were not elevated to phytotoxic or unsafe amounts for human or animal consumption. However, the effects of prolonged disposal of oily wastes on wheat grown in the treated soil are still indeterminate.

Conclusions

The data obtained by SCS Engineers are generally in agreement with those found by the oil company (Huddleston, personal

TABLE 8. CHEMICAL CHARACTERISTICS OF THE CONTROL AND OIL-TREATED SOILS AT OKLAHOMA SITE

Parameter	Control Soil Depth (cm)		Treated Soil Depth (cm)	
	0-30	30-60	0-30	30-60
pH	6.6	6.3	7.0	6.2
EC, mmhos/cm	1.0	0.8	2.9	1.6
Total N, %	0.10	0.09	0.13	0.09
	- - - - - - - - 0.1N HCl-Extractable, µg/g - - - - - -			
Ortho-P	5.6	0.8	6.3	0.7
SO_4	18.7	12.5	625	212
Mo	0.27	0.22	0.24	0.26
Fe	6.8	8.8	9.8	7.2
Mn	22.3	7.6	70	9.7
Cu	0.5	0.7	26.8	1.3
Ni	1.0	0.9	2.3	0.5
Pb	1.2	0.1	160	1.7
Cr	0.08	0.08	11.3	0.2
Cd	0.03	0.01	0.11	0.01
Co	0.20	0.17	0.62	0.22
Ag	0.06	0.08	0.17	0.03
Al	140	130	135	155
Ti	0.35	0.80	2.90	0.85
Zn	1.5	1.6	118	2.6
	- - - - - - - - - Water-Soluble*, µg/ml - - - - - - -			
B	<0.2	<0.2	<0.2	<0.2
Na	5	7	76	47
K	29	8	39	17
Ca	151	106	710	250
Mg	28	43	120	88
Cl	50	78	33	50
SAR	0.09	0.15	0.69	0.64

* Measured in the water saturation extracts.

TABLE 9. CHEMICAL ANALYSES OF WHEAT GRAIN FROM THE CONTROL AND TREATED PLOTS AT OKLAHOMA SITE

Element	Control Plot*	Treated Plot No. 1	21	27	Avg.
			%		
N	2.74	2.40	1.11	1.16	1.57
P	0.32	0.33	0.34	0.34	0.33
K	0.41	0.38	0.36	0.39	0.38
			μg/g		
B	1.38	2.75	2.75	2.12	2.54
Mo	1.69	2.45	4.33	3.39	3.39
Fe	48.3	55.0	48.3	50.4	51.2
Mn	21.67	37.50	41.25	40.00	39.58
Cu	3.81	5.38	5.75	5.38	5.50
Ni	2.5	5.0	5.0	2.75	4.25
Pb	<0.05	1.0	<0.05	1.23	--
Cr	0.42	3.13	2.5	2.92	2.85
Cd	0.11	0.15	0.18	0.20	0.18
Co	0.19	0.06	0.15	0.06	0.09
Ag	0.33	0.33	0.29	0.13	0.25
Al	0.68	0.50	1.40	1.31	1.07
Ti	0.73	0.26	0.73	0.38	0.46
Zn	61.0	72	73.75	70.0	72.17

* Composite was made from plot Nos. 2, 16, and 26 samples.

communication). Based on the first-year results, the following conclusions can be drawn:

- Application of oily waste significantly increased the concentrations of heavy metals in the surface soil. To a lesser extent, plant uptake of these metals was also increased, but metal concentrations had not reached phototoxic levels.
- No significant movement of heavy metals beyond the zone of incorporation was found.
- Oil treatment decreased the nitrogen content in the wheat.

TEXAS

Introduction

The various types of refinery waste and current disposal technologies for such wastes are discussed previously with the Oklahoma site. The Texas site differs from the Oklahoma site in the following aspects:

- Different waste (API separator sludge) and soil types
- Longer site operation history
- No crops grown
- Greater precipitation than at the Oklahoma site.

The objective of this field study was to determine the effects of land application of oil refinery waste on soil properties (including heavy metal accumulation) and on plant uptake of heavy metals.

Site Description

The site is located in southeast Texas near the Gulf of Mexico. The refinery occupies about 1,315 ha (3,000 ac) of land and refines 64,000 m^3 (400,000 bbl) of oil daily.

Two land cultivation areas are located within the refinery complex, approximately 0.8 km (0.5 mi) from the waste sources. The older area, 6.1 ha (15 ac) in size, has been abandoned for several years. The newer cultivation site consists of two 4.1-ha (10-ac) plots (Figure 7), one that has been in use for 4 yr, the other for 7 yr. Neither plot had received fertilizer or pesticide applications. Dikes were built along the perimeter of the plots to prevent surface runoff of oil-contaminated water. Common vegetation in and around the plots includes nutgrass, crabgrass, cockleburs, and unidentified weeds.

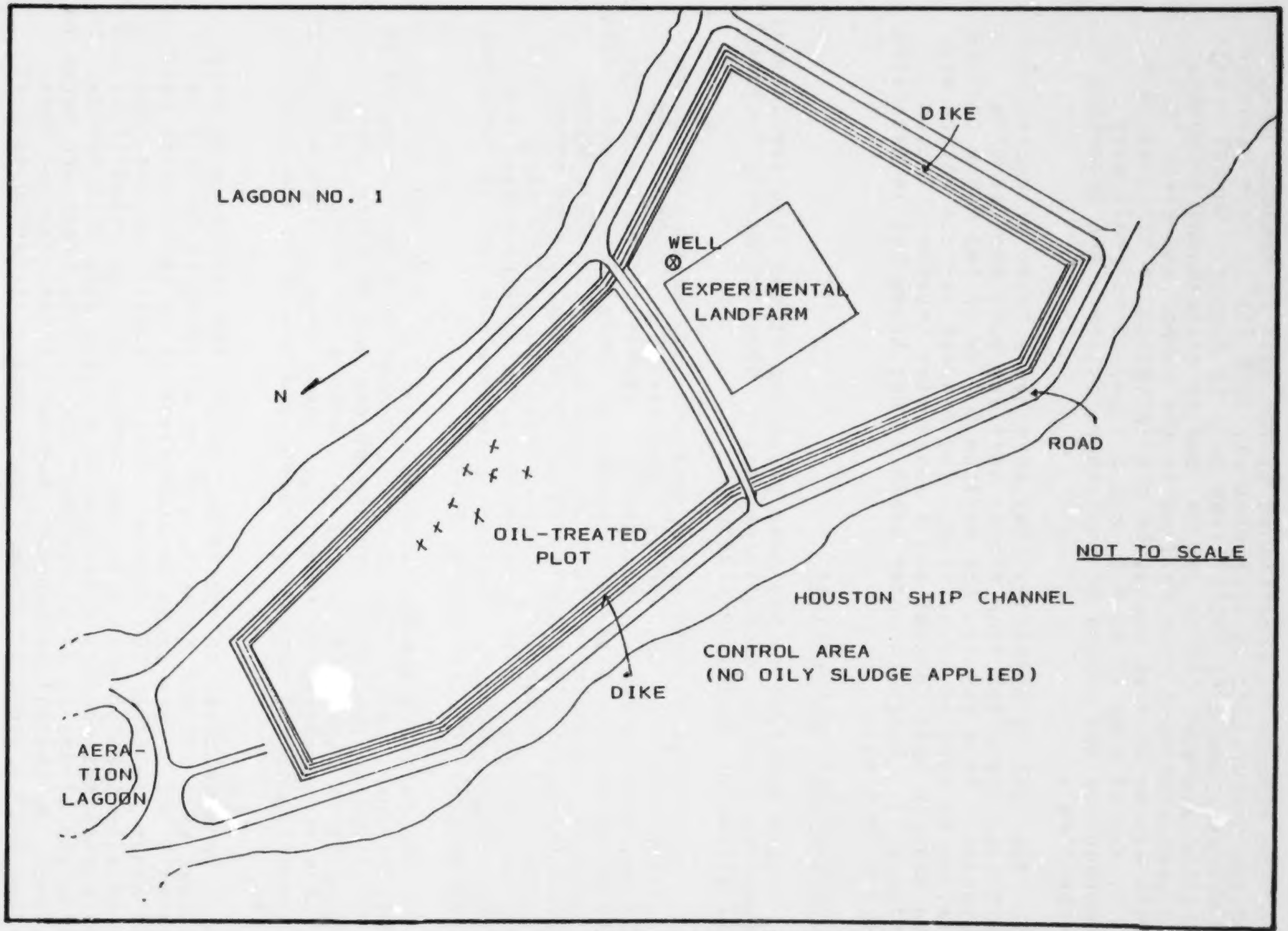

LAGOON NO. 1
DIKE
WELL
EXPERIMENTAL LANDFARM
N
ROAD
OIL-TREATED PLOT
NOT TO SCALE
HOUSTON SHIP CHANNEL
CONTROL AREA
(NO OILY SLUDGE APPLIED)
DIKE
AERA-TION LAGOON

Figure 7. Landfarm area, Texas site.

The climate is conditioned by the Gulf of Mexico. The average temperature is approximately 12°C (55°F) from November to February and 26°C (80°F) from July to August. Annual precipitation averages 121 cm (48 in) and is distributed throughout the year with more rain falling in the summer and early fall. There was an unusual amount of precipitation in 1976, as 18.5, 11.7, and 15.5 cm (7.3, 4.6, and 6.1 in) of rainfall were recorded for the months of September, October, and November, respectively.

The soil is primarily clay that has a layer of coarse soil particles deposited from either settling pond muds or dike material. As a result, the surface 5.1 cm (2 in) has a texture similar to that of loamy sand. The nearest surface waters are the Houston Ship Channel and a wastewater treatment lagoon (Figure 7). Depth to water table is not known but is estimated at 3 m (9.8 ft).

Land Cultivation Practices

Land cultivation has been practiced at the site for several years for disposal of refinery wastes, which primarily include API oil-water separator sludges.

An average API oil-water separator sludge consists of an emulsion with 8.3, 58, and 33.7 percent of oil, water, and solids, respectively. The chemical composition of the sludge deposited at this site is presented in Table 10. Concentrations of copper, chromium, nickel, and zinc are higher than values normally reported for soils, while concentrations of other elements are either lower than or equal to soil values. Since the oily sludge is alkaline (pH 8.1), it is likely that the heavy metals would be retained in the surface soil in forms not readily available for plant uptake.

The refinery generates about 29,600 m^3 (185,000 bbl) of oily sludge a year. The sludge is pumped from the bottom of an API oil-water separator into one of the two settling pits, where it is stored for 1 or 2 yr. When a pit is full, the sludge is dewatered by decanting. The sludge is then removed by clamshell, loaded onto dump trucks, and hauled to the landfarm area.

Land cultivation operations entail the spreading of oily sludge with a track dozer to a depth of about 10 to 12.5 cm (4 to 5 in). This depth is equivalent to an application rate of about 224 t/ha (100 tons/ac). After partial drying, the sludge is incorporated into the surface soil by rototilling and by subsequent monthly disking with a heavy duty disk harrow. When the sludge is first applied, the soil is black and tends to clump. As the oil decomposes, the soil turns gray and then brown with a loose or powdery appearance. According to past

TABLE 1a CHEMICAL COMPOSITION OF API
OIL-WATER SEPARATOR SLUDGE AT TEXAS SITE*

Element	Conc. (µg/g)†	Constituent	Conc. (%)
			by weight
N	400	Oil	8.3
P	222	Water	58.0
K	80	Solids	33.7
Na	410		
Ca	5,900		
Mg	1,600		
Ba	140	Oil Fractions	by volume
As	4	Normal and branch paraffins	46.7
B	3		
Cd	0.42	Aromatics	46.7
Cr	640	Polycyclies	6.6
Hg	3		
Mn	83	pH	8.1
Ni	102	Specific gravity	1.55 @ 80°F
Pb	80		
Zn	331		
Cl	195		

*Analyzed by the company laboratory (August 1976).

†Dry weight basis.

experience, when the oil content of the surface soil has decreased to about 2 to 4 percent, the soil is deemed ready to receive the next application.

The estimated cost of waste disposal by this land cultivation method is \$3.90 to \$10.50/m^3 (\$3 to \$8/yd^3), including cost for dredging and transporting sludge from settling pits to the disposal site. An additional \$11,000/yr is spent on site management.

Field Sampling and Chemical Analyses

Field Sampling--

Soil and vegetation sampling was conducted in November 1976. Ten soil samples from the surface layer (0 to 15 cm) were taken randomly from various spots within the disposal or treated plot. Ten samples were taken from the same dpeth at off-site control plots where similar plant species were growing in untreated soil. (Sampling spots are marked by X's on Figure 7). A portion of soil from each group of 10 samples was combined to make a composite sample. In-depth investigations of the impact of land cultivation of refinery wastes on soil, groundwater and surface waters and on the prevalent vegetation were not within the scope of this project.

Cocklebur and nutgrass, the two common types of vegetation in the area, were sampled from the same locations where the soil samples were obtained. A composite was made for each type of vegetation prior to processing the samples.

Chemical Analyses--

Soil and plant composite samples were processed and analyzed for selected plant nutrients, trace elements, and heavy metals, according to the procedures described in the Appendix.

Soil analyses--Chemical analysis of the surface soil (0 to 15 cm deep) indicated that soil from the oil-treated plot contained higher levels of soluble salts, TKN, and organic carbon than soil from the off-site control plot (Table 11).

Concentrations of HCl-extractable sodium, zinc, and selenium increased considerably, while those of other trace elements increased only slightly from land cultivation of oil refinery waste (Table 11). The lead levels in the treated and control soils were high. The explanation may be that lead content is naturally high in the soil around the disposal site; or the control plot may have been previously contaminated with the oily sludge, which was high in lead. Another possibility is that the lead may be from the local atmosphere which, due to automobiles, may have a high lead concentration. As discussed

TABLE 11. CHEMICAL CHARACTERISTICS OF THE CONTROL AND OIL-TREATED CLAYEY SOIL AT TEXAS SITE

Parameter*	Control	Treated
pH	7.41	7.40
EC, mmhos/cm	2.21	3.91
Oil, %		2.06
TKN, %	0.080	0.134
Org. C, %	2.10	5.10
	ppm	
P	17.5	17.5
Na	185	375
B	0.2	0.22
Mn	65	71.6
Ni	4.8	5.3
Zn	53.5	71.5
Se	0.01	0.028
Mo	0.6	0.55
Cd	0.06	0.06
Pb	212	242

*Electrical Conductivity (EC) and B (μg/ml) were measured in the saturation extracts; other elements in ppm (μg/g) were determined in 0.1N HCl extracts.

later, vegetation in the area also accumulated large amounts of lead.

Plant analyses--Vegetative samples were taken from nutgrass leaves and cocklebur seeds. Nutgrass was considerably younger in the oil-treated plot than in the control plot, while cocklebur from both treated and control plots was of about the same age when the samples were taken. Cocklebur seeds were selected for analysis since the leaves were old and dry at sampling time.

Land cultivation at this site increased sodium, boron, nickel, zinc, molybdenum, and lead concentrations in the nutgrass (Table 12); differences in these elements were not as marked in cocklebur seeds. Except for nitrogen, phosphorus, and boron, trace element concentrations in cocklebur seeds were lower than those found in nutgrass tissues.

Concentrations of zinc, nickel, and, in particular, lead were high in nutgrass grown on the oil-treated plot. The lead values are comparable to the lead concentrations in pasture grasses in a lead-contaminated area near Antioch, California (Ganje, personal communication). Normal lead concentrations in the leaves and seeds of agronomic and vegetable crops are generally less than 15 ppm and 5 ppm, respectively. The data suggest that nutgrass and cocklebur seeds have accumulated significant amounts of lead, particularly from oil-treated plots.

Summary

To obtain basic data on the possible environmental impact of land cultivation of an API sludge at the Texas site, surface soil and natural vegetation were sampled and analyzed for chemical characteristics and elemental composition.

Soil analyses indicate that land cultivation of the oily waste increased soluble salts, TKN, and organic carbon in the soil. Concentrations of HCl-extractable sodium, zinc, and lead were also increased from waste application. The data identify the accumulation of lead in soil; however, the extent of lead contamination is not known, since background samples are also high.

Analyses of nutgrass leaves and cocklebur seed collected at the site show that concentrations of zinc, nickel, molybdenum, and lead are significantly higher in the treated than in the control plots. The lead concentrations are also higher regardless of waste application, which is indicative of vegetative contamination by lead in the general vicinity of the site.

TABLE 12. CHEMICAL ANALYSIS OF NUTGRASS AND COCKLEBUR SEEDS SAMPLED FROM THE CONTROL AND OIL-TREATED PLOTS AT TEXAS SITE

	Nutgrass		Cocklebur Seed	
Element	Control	Treated	Control	Treated
	- - % - -		- - % - -	
N	1.44	1.42	3.05	1.07
P	0.17	0.11	0.29	0.16
	- - μg/g - -		- - μg/g - -	
Na	2,062	6,187	1,000	687
B	7	15	28	14
Mn	63.6	48.7	18.8	19.1
Ni	1.9	6.3	3.6	3.1
Zn	93.8	131.9	43.8	53.1
Se	0.23	0.23	0.04	0.04
Mo	7.1	9.5	4.2	8.7
Cd	0.41	0.41	0.15	0.15
Pb	61.5	90.5	11.2	23.2

SECTION 3

CASE STUDIES OF LAND CULTIVATION PRACTICES

OVERVIEW

To gain more practical and in-depth knowledge about operational aspects of land cultivation, six active sites were visited. During these visits, management and operating personnel were interviewed, walking surveys of the cultivation area were conducted, and operational activities were observed. Information obtained from these visits was then compiled into the case study reports that follow. Five of the case studies are presented in detail, with the sixth (the Michigan site) presented as a much less detailed "mini" case study.

Site selection was based on obtaining a representative sampling of waste types, and on climatic conditions. The matrix in Table 13 indicates in general terms the waste and climate at each of the six case study sites.

TABLE 13. BASIC CHARACTERISTICS OF LAND CULTIVATION CASE STUDY SITES

Site	Waste Type	Climate
Southern California	Oily	Dry, mild all year
Illinois	Mixed industrial	Wet, cold winters and hot summers
Rhode Island	Organic chemicals	Wet, cold winters and hot summers
Indiana	Soap and detergent	Wet, cool winters and hot summers
Odessa, Texas	Municipal refuse	Dry, cool winters and hot summers
Michigan	Pulp and paper	Wet, cold winters and cool summers

Information presented in each case study report includes a description of the site and the waste; a history of activities; method of waste application and storage; environmental factors; state regulations; a summary of equipment, personnel, and costs; planned final site use; and public response and problems encountered.

Each site has encountered problems to varying degrees. In general, the problems have tended to be unique to each site and were not insurmountable. Odor problems have been noted at several sites; different mitigation measures were taken to solve this problem. No other significant environmental problem has been detected by existing monitoring programs or by state and local regulatory agencies. In terms of economics, persons involved with each of the six operations generally feel that land cultivation offers cost benefits when compared to the other viable alternative methods of waste disposal.

Of the six states represented in the study, only Texas has specific regulations that address industrial wastewater/sludge disposal by land cultivation. However, the Texas regulations do not cover the municipal solid waste being land cultivated at Odessa. Therefore, each of the six case study sites has been handled by the appropriate state and local regulatory agencies on an individual review basis.

SOUTHERN CALIFORNIA

Summary

Land was acquired at this site over 20 yr ago for the disposal of oily wastes, which are now produced by about 15 oil companies operating in the area. These wastes are primarily drilling muds, although oil and water mixtures from oil storage tank bottoms contribute substantially to the waste input. Some oil spill debris has also been disposed of at this site. Land cultivation of the oily wastes has been practiced since 1959.

The site is located 365 m (1,200 ft) from the Pacific Ocean on a wide alluvial plain. Shallow perched groundwater underlies the site at 9.1 m (30 ft); the aquifer which supplies drinking water to the area underlies the site at 60 m (200 ft). Oil migrating vertically from the disposal area can reach the perched water but not the aquifer. The only nearby surface water is the Pacific Ocean to the west of the site.

Previous investigations at the site (23) indicate that some oil may be migrating from the upper layers of the land cultivation area to the perched water below. However, the disposal site may not be the sole source of this oil.

The original loose sand at the site has been transformed into a dark, silty sand by microbial decomposition of the oil and by the presence of large volumes of waste drilling muds in the input waste. Soil is more consolidated in the disposal area and supports scattered vegetation as allowed by dozer activity. Those portions of the site that have been idle for several years show no signs of oil in the soil and have no hydrocarbon odor.

Chemical analyses of soil samples collected at the site indicated significant increases in pH, TKN, organic carbon, sodium, soluble salts, boron, and levels of HCl-extractable nickel, manganese, zinc, and lead in the treated soil. Plant uptake of sodium, manganese, zinc, and lead from the treated soil also increased.

History of Land Cultivation Activities

In 1954, 12 ha (30 ac) of beach land were leased to a private contractor for use as an oily waste disposal site. The land consisted of Pleistocene sand dunes, still visible to the west of the site. This area was first utilized as an oil sump, where oily wastes were lagooned until 1959. In 1959, another 14 ha (35 ac) were leased directly west of the original property. Land cultivation operations began in both areas, and the wastes were mixed with indigenous sands. Surrounding land was used primarily for agricultural and, more recently, for residential purposes. The original contractor is still active at the site.

Site Description

The site is located approximately 113 km (70 mi) northwest of Los Angeles on the Southern California coast. Figure 8 indicates the general area of the site. Oily wastes have been disposed of on the site since 1955; land cultivation has been practiced since 1959.

Land Area and Topography--

The site contains a total of 26 ha (65 ac), with current land cultivation activities confined to a 12-ha (30-ac) parcel of land on the western side of the plot. Figure 9 shows the layout of the site and indicates the area of current activities. Vacuum trucks used to transport wastes enter the site by a dirt road on the south side.

Topographically, the site is located at the mouth of a wide, relatively level alluvial plain that empties into the Pacific Ocean. The site itself exhibits a gradual western sloping relief of approximately 1.5 to 3 m (5 to 10 ft) due primarily to on-site grading.

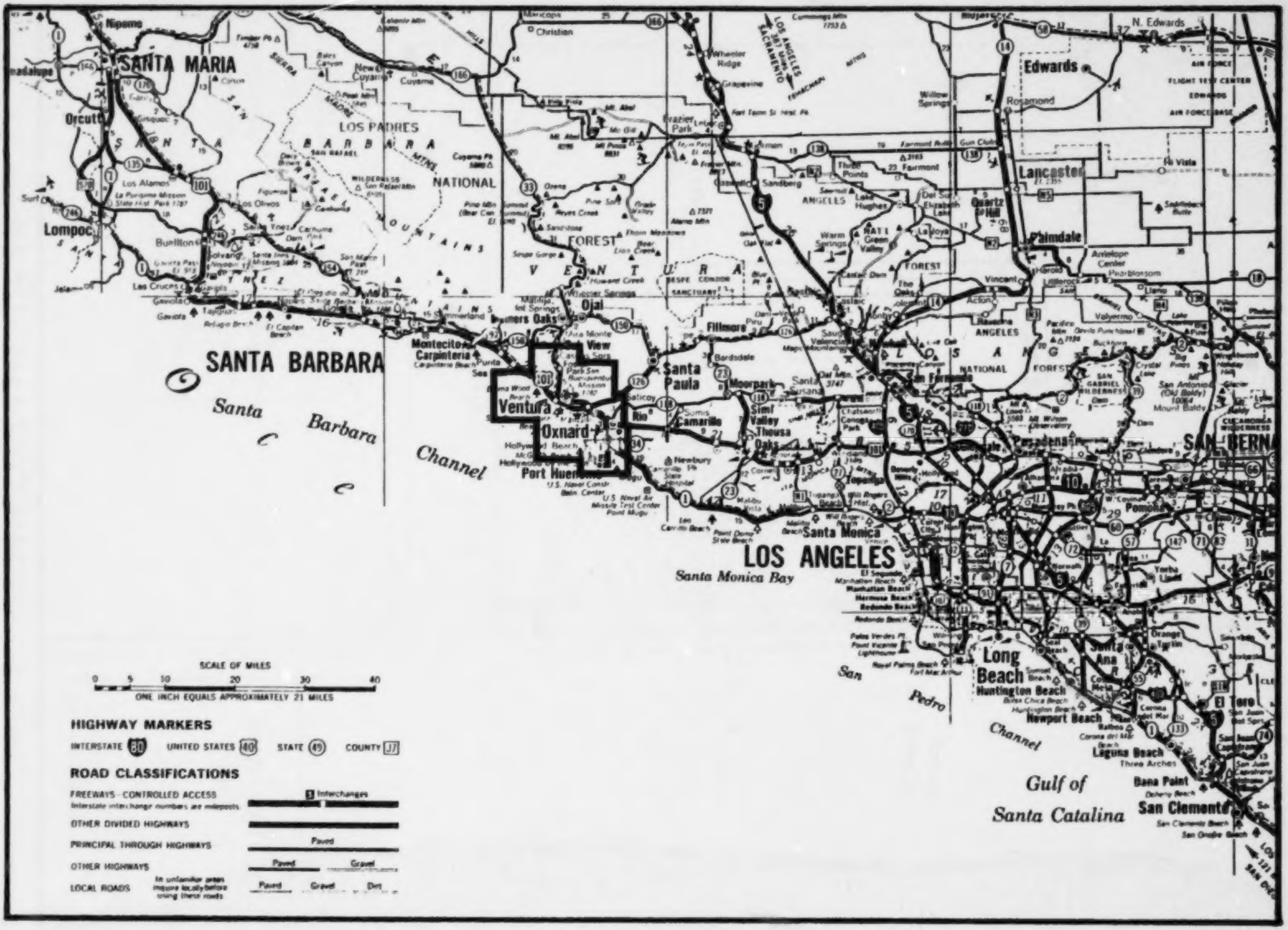

SANTA MARIA
Orcutt
Lompoc
SANTA BARBARA
Santa Barbara Channel
Ventura
Oxnard
Port Hueneme
Ojai
Santa Paula
Fillmore
Moorpark
Camarillo
Simi Valley
Thousand Oaks
LOS ANGELES
Santa Monica
Santa Monica Bay
Long Beach
Huntington Beach
Newport Beach
Santa Ana
Laguna Beach
San Clemente
El Toro
San Pedro Channel
Gulf of Santa Catalina
Pasadena
Pomona
SAN BERNA
Lancaster
Palmdale
Edwards
LOS PADRES NATIONAL FOREST
ANGELES NATIONAL FOREST
SCALE OF MILES
0 5 10 20 30 40
ONE INCH EQUALS APPROXIMATELY 21 MILES
HIGHWAY MARKERS
INTERSTATE 80
UNITED STATES 40
STATE 49
COUNTY J7
ROAD CLASSIFICATIONS
FREEWAYS - CONTROLLED ACCESS
Interstate interchange numbers are mileposts
Interchanges
OTHER DIVIDED HIGHWAYS
PRINCIPAL THROUGH HIGHWAYS
Paved
OTHER HIGHWAYS
Paved
Gravel
LOCAL ROADS
In unfamiliar areas inquire locally before using these roads
Paved
Gravel
Dirt

Figure 8. Location of Southern California site.

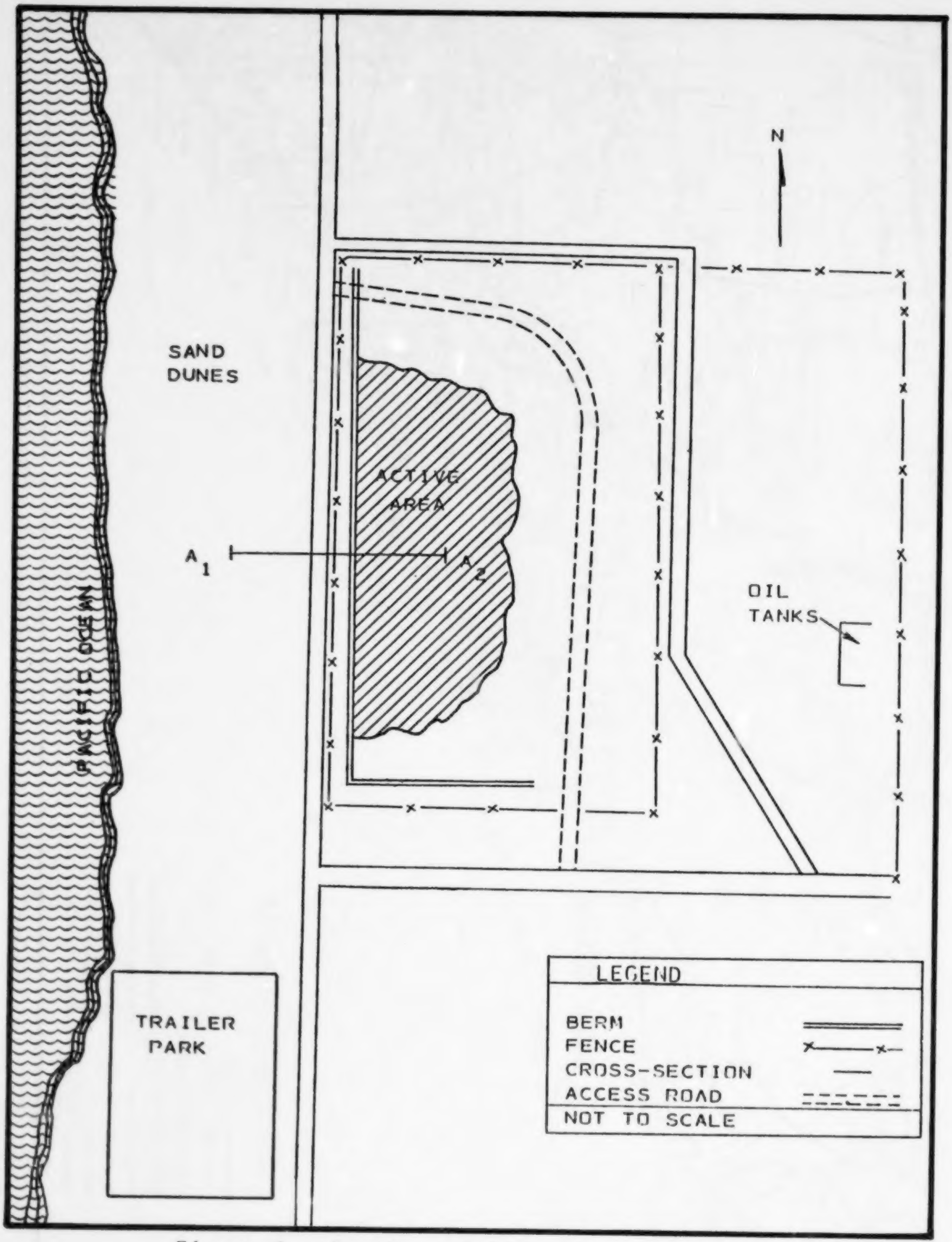

PACIFIC OCEAN
SAND DUNES
N
ACTIVE AREA
A1
A2
OIL TANKS
TRAILER PARK
LEGEND
BERM
FENCE
CROSS-SECTION
ACCESS ROAD
NOT TO SCALE

Figure 9. Southern California site map.

Surface Drainage Patterns, Surface Water and Groundwater--

The site is located approximately 365 m (1,200 ft) from the Pacific Ocean, which is the only significant surface water in the area. All drainage is in a westerly direction toward the ocean. To contain runoff on site, a 1.8-m (6-ft) earthen berm has been constructed on the west and south sides of the site.

The surface hydrology consists of limited runoff in a westerly direction during periods of intense precipitation. Runoff is limited due to high permeability of the sandy surface soils and the relatively flat topography.

Subsurface hydrology consists of: (1) shallow perched water at a depth of about 9.1 m (30 ft), and (2) an aquifer at a depth of about 60 m (200 ft). The aquifer, rather than the perched water, is a water supply for the area. Since there is no hydraulic continuity between the aquifer and the perched water, any infiltration of oily wastes could affect only the perched water. Characteristics of the perched groundwater system are addressed below.

The perched water table is defined vertically by the impermeable sediments and horizontally by the ocean and inland sediments. Since there is little or no contributing recharge from the inland sediments, precipitation and runoff are the only recharge sources of this perched water. Seasonal fluctuations in the water level are radical, ranging from several meters above the aquiclude to total saturation of the sands during periods of intense precipitation. Movement of this perched water is assumed to be seaward where discharge occurs. Figure 10 illustrates the estimated groundwater elevations and direction of movement based upon static water levels on March 19, 1976. Conductivity readings of the perched water show a TDS value of 25,000 ppm, attesting to probable salt water intrusion when hydraulic gradients permit.

Vegetation and Soil--

Natural vegetation at the site includes ragweed, golden brush, ice plant, and various tall grasses. No vegetative cover has been planted since the nearly continuous land cultivation activities preclude establishment of such cover. Native vegetation is very sparse and scattered and is found primarily around the edges of the cultivated area.

Information on the site's soils, geology, and hydrology was obtained from available published reports and from observations during well borings on March 19, 1976, performed as part of an earlier project (23).

The United States Geological Survey defines the area of the land cultivation operation as inactive dune sands that parallel the ocean for several miles north and south of the site (24). These fine sands extend inland approximately 914 m (3,000 ft) where they contact fine-grained, relatively impermeable, alluvium sediments of Pleistocene Age (see Figure 10). The dune sands are relatively uniform in size, possibly enhancing the adsorption of percolating waste oils and subsurface aeration. Sand depths are approximately from 4.5 to 9.1 m (15 to 30 ft) in this area. A typical soil profile to a depth of 9.0 m (30 ft) is shown on Figure 11. The first 4.6 m (15 ft) is derived from sieve analyses. Figure 12 shows the well logs for all wells drilled at the site.

Below the permeable dune sands are several centimeters of unconsolidated cobble-sized gravels, which were encountered in three of the well hole corings at the site. An impermeable layer of clastics from 45 to 60 m (150 to 200 ft) thick underlies these gravels and provides an effective aquiclude for any further vertical infiltration of waters.

Climate--

Climate at the site is typical of the Southern California coastal area: summers and winters are mild and there is little precipitation. Climatological data is summarized in Table 14 (25). Temperature varies from lows of 6°C (42°F) to highs of 23°C (73°F) (26). Annual precipitation averages about 32 cm (13 in), which falls primarily in the rainy season between November and April. Westerly winds prevail.

Related Studies

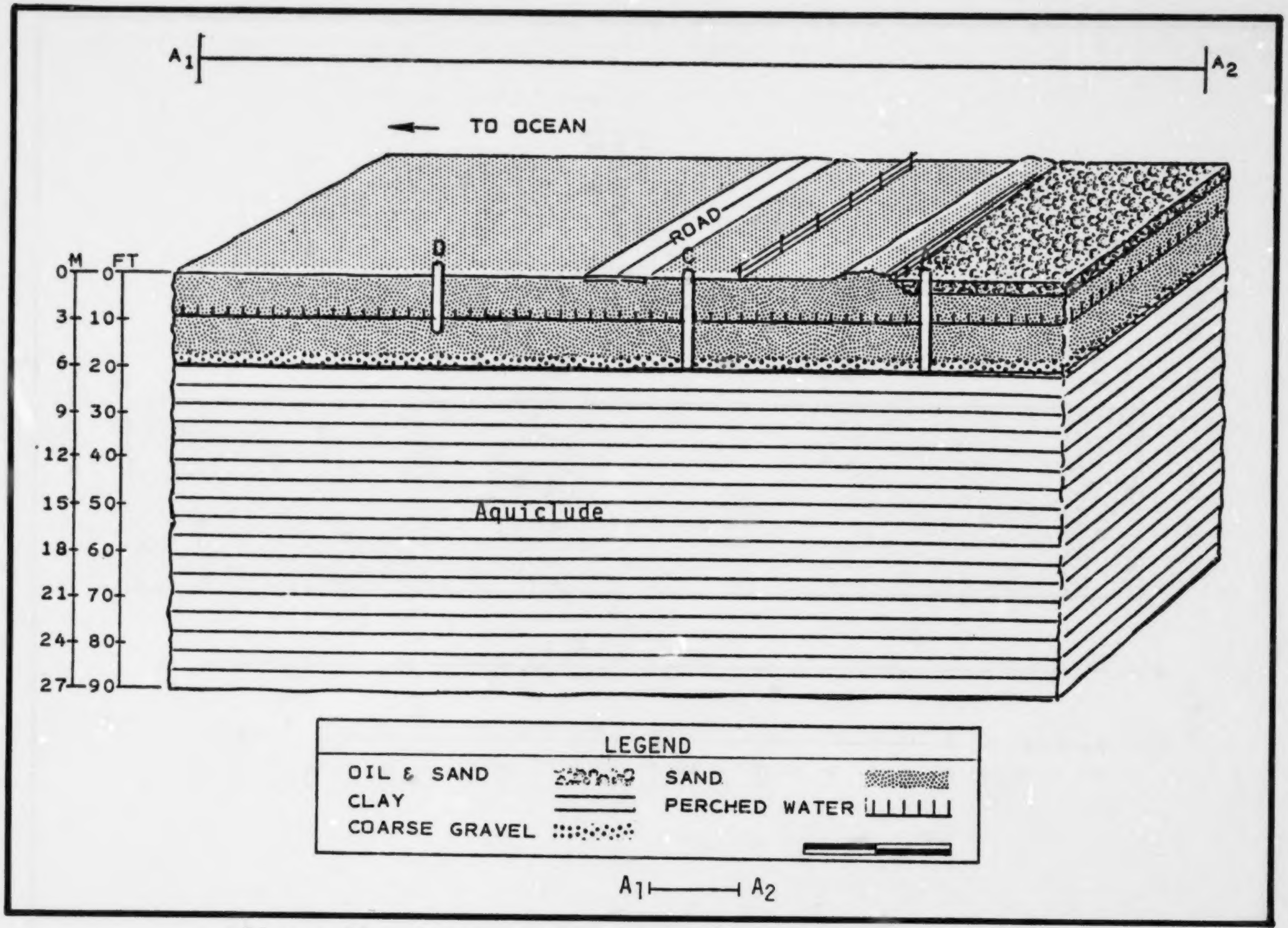
This site was previously studied in depth to determine the impacts of oil spill debris disposal on local groundwater. Results of that study are reported in detail in Reference 23 and are summarized under "Environmental Factors."

State Regulation

Regulations of the California Water Quality Control Board, Los Angeles office, apply to operations at this site. The role of the board is discussed under "Environmental Factors."

Waste Characteristics

Since 1959, the site has received various types of oily wastes from the area's many oil companies. Drilling muds, as well as oil and water mixtures from storage tank bottoms, have constituted the largest portion of these wastes. Oil content in the drilling muds, previously about 10 percent, has recently decreased to about 5 to 7 percent. Some oil spill debris from the Santa Barbara oil spill of 1969 has also been accepted at the site, although specific quantities or locations of deposition are unknown. Most of the oils within the oily wastes have been crudes, although specific origins and oil types are nearly


A1
A2
TO OCEAN
ROAD
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3
6
9
12
15
18
21
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27
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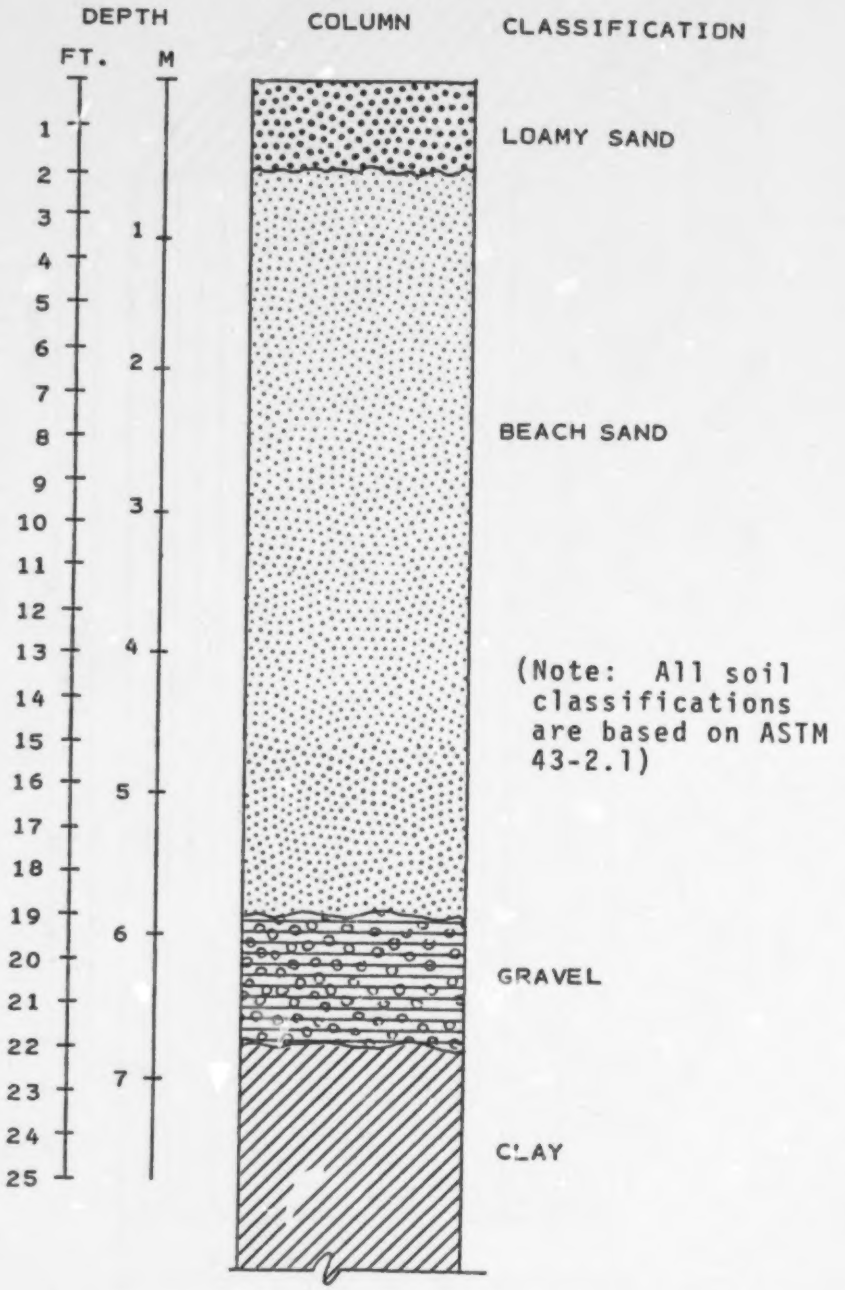
10
20
30
40
50
60
70
80
90
Aquiclude
LEGEND
OIL & SAND
CLAY
COARSE GRAVEL
SAND
PERCHED WATER
A1
A2

Figure 10. Cross section of Southern California site.


DEPTH
FT.
M
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23
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25
1
2
3
4
5
6
7
COLUMN
CLASSIFICATION
LOAMY SAND
BEACH SAND
(Note: All soil classifications are based on ASTM 43-2.1)
GRAVEL
CLAY

Figure 11. Soil profile based upon sieve analysis.

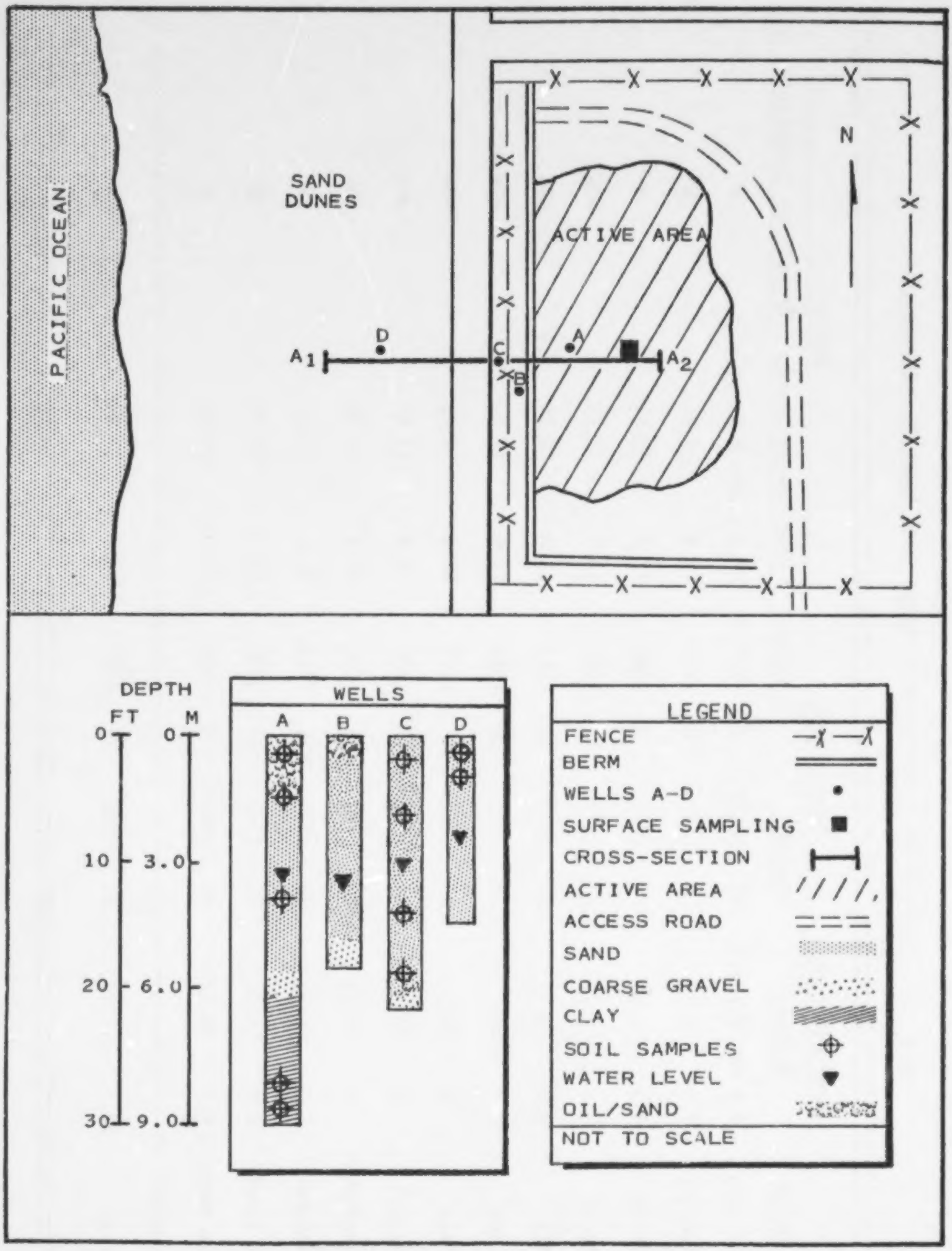

PACIFIC OCEAN
SAND DUNES
ACTIVE AREA
N
D
C
A
B
A1
A2
DEPTH
FT
M
0
10
20
30
0
3.0
6.0
9.0
WELLS
A
B
C
D
LEGEND
FENCE
BERM
WELLS A-D
SURFACE SAMPLING
CROSS-SECTION
ACTIVE AREA
ACCESS ROAD
SAND
COARSE GRAVEL
CLAY
SOIL SAMPLES
WATER LEVEL
OIL/SAND
NOT TO SCALE

FIGURE 12. WELL LOGS

TABLE 14. SUMMARY OF CLIMATOLOGICAL DATA: LOS ANGELES, CALIFORNIA

	Precipitation	Temperature		Winds	
Month	Normal	Maximum	Minimum	Mean Hourly Speed	Prevailing Direction
January	6.8 cm (2.7 in)	18°C (64°F)	7°C (45°F)	10.6 kmph (6.6 mph)	W
February	7.3 (2.9)	18 (64)	8 (47)	11.6 (7.2)	W
March	4.5 (1.8)	18 (65)	9 (49)	12.7 (7.9)	W
April	2.7 (1.1)	19 (67)	11 (52)	13.4 (8.3)	WSW
May	0.3 (0.1)	20 (69)	13 (55)	13.0 (8.1)	WSW
June	0.1 (0)	22 (71)	15 (58)	12.6 (7.8)	WSW
July	0 (0)	24 (76)	17 (62)	11.9 (7.4)	WSW
August	0 (0)	24 (75)	17 (63)	11.9 (7.4)	WSW
September	0.4 (0.2)	24 (76)	16 (61)	11.3 (7.0)	WSW
October	1.0 (0.4)	23 (73)	14 (57)	10.6 (6.6)	W
November	2.8 (1.1)	22 (71)	11 (51)	10.5 (6.5)	W
December	6.1 (2.4)	19 (66)	8 (47)	10.5 (6.5)	W
Year	32.1 (12.6)	21 (70)	12 (54)	11.7 (7.3)	W

impossible to define. The oily wastes receive no pretreatment before disposal at the site.

Records of waste type and volume received have been maintained, as required by the California Regional Water Quality Control Board, Los Angeles. According to these records, daily amounts of oily waste received have ranged from 2.3 to 168 m^3 (15 to 1,060 bbl) per day. Recently, cultivated quantities of oily waste have averaged approximately 3,200 m^3 (20,000 bbl) per month. Figure 13 presents the annual waste quantities for the years 1960 through 1976. The site operator indicated that for the early part of 1977, input waste quantities averaged from 4,000 to 5,000 m^3 (25,000 to 30,000 bbl) monthly. In this 17-yr period, a total of over 530,000 m^3 of oily wastes have been cultivated at this site.

Waste Application

The land cultivation procedures used at the site have evolved by trial and error over its 22-yr operating history. Site maintenance plays an important role in the land cultivation operation. All active areas of the site are maintained level so that ponding and runoff are minimized.

All wastes are transported to the site by truck. The access road used by waste delivery trucks is graded and maintained in good condition. Slopes from this road to the active area are kept at about a 10 percent minimum so that the oily wastes can gravity flow from the trucks onto the level active area (see Figure 14).

After the oily waste is deposited in the working area, a track dozer mixes it with sand and previously deposited oily waste to promote aeration and contact with oil-consuming bacteria. Figure 15 shows the track dozer and a recently mixed plot. The dozer operator mixes the oil material with the sandy soil by the combined action of pushing with the blade and churning up the soil with the tracks. Several passes over the plot are usually sufficient for thorough mixing. A disk harrow is used less than 5 percent of the time. Under environmental conditions usually prevailing at the site, the blade provides sufficient mixing. Mixing is halted only during periods of very heavy rain.

Small dikes are constructed that divide the larger site into smaller plots of 1.6 to 2 ha (4 to 5 ac). Oily wastes are dumped from the vacuum trucks into a small plot for approximately 2 wk, until a total waste input of 1,900 to 2,400 m^3 (12,000 to 15,000 bbl) has accumulated. From 1 to 4 wk are required, depending on weather conditions, for the waste to dry sufficiently for the dozer to work the plot with its blade. This operation mixes waste and soil to a depth of 46 to 61 cm (18 to

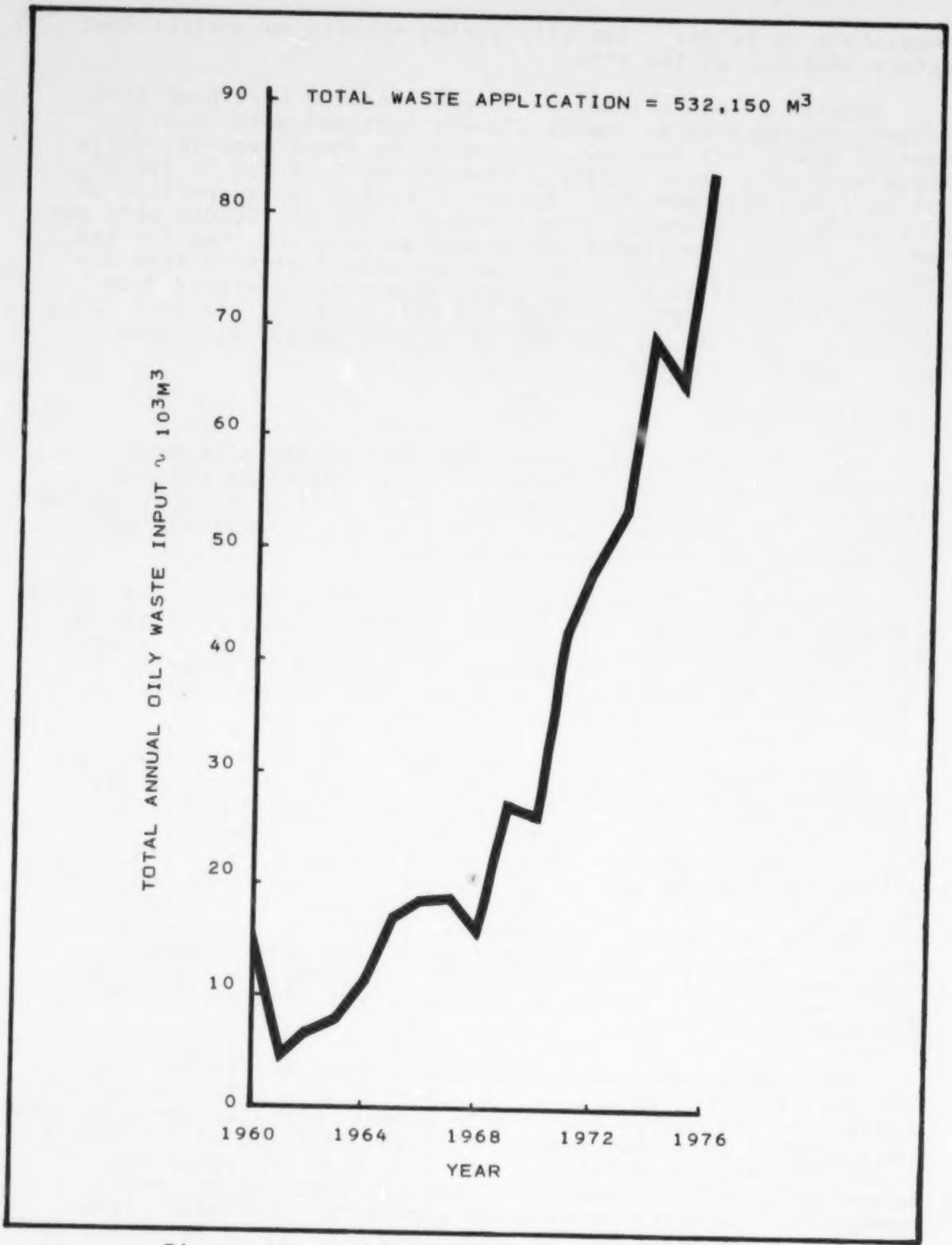


Figure 13 . Historical waste quantities.

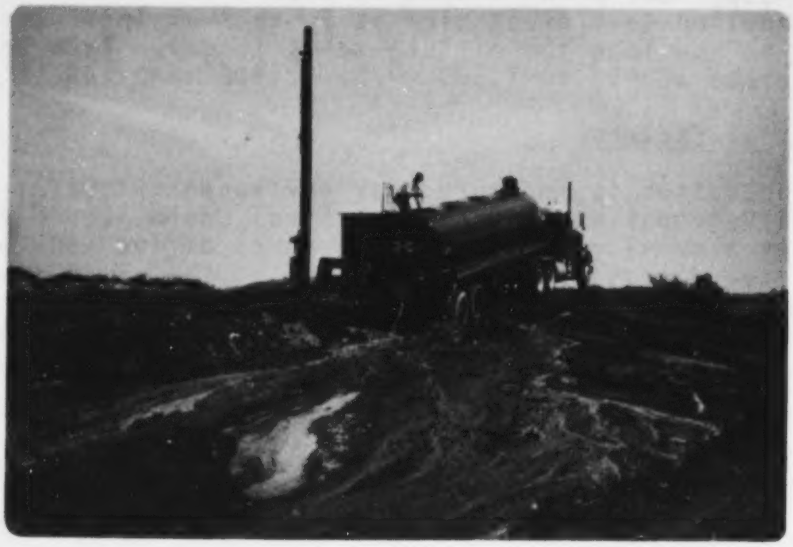


Figure 14. Oily wastes deposited at Southern California site.

Figure 15. Mixing of oily wastes and sands at Southern California site.

24 in). After this mixing operation, the plot is sufficiently dry that reapplication of wastes is possible. Thus, oily wastes can be reapplied to a given plot at 3- to 7-wk intervals, depending on how long the mixture takes to dry. Each application is at the rate of 950 to 1,500 m^3/ha (2,400 to 3,750 bbl/ac).

Environmental Factors

The operation is monitored for environmental safety by the California Regional Water Quality Control Board, Los Angeles. This agency also maintains monthly records of the volume and origin of the deposited wastes. Review of this agency's field notes and discussions with field investigators indicate that only a few minor difficulties have been noted during the 22 yr of operation.

A monitoring program was previously devised for the site to determine the following:

- Environmental impacts of oily waste disposal by land cultivation in coastal California's climate

- The degree to which oil is decomposed by the soil microorganisms.

To implement this monitoring program, four wells were drilled at site locations and depths noted on Figure 12. Well A was drilled within the active area; Well B, in a recently active but then idle area; and Wells C and D, off site and downhill from the other wells. Water samples were later taken from each well for analysis of several parameters, listed in Table 15.

During well drilling, soil samples were taken at several depths, as shown on Figure 12. All soil samples taken during well drilling were packed in ice and returned to the laboratory for analysis. Then once per week for the following 5 wk, a sample of soil/oil mixture was taken for analysis from the surface or from just below the surface. The sampling point was approximately 4.5 m (15 ft) south of Well A.

Tables 15 and 16 present the results of the various analyses performed on oily soil and groundwater samples obtained from Site A. Data in Table 15 pertains to samples taken on March 19, 1976. Table 16 presents data on subsequent surface soil/oil samples.

Review of the analytical results in Tables 15 and 16 indicates that oil may be migrating from the upper layers of the land cultivation area to the perched water below. However, the data is not extensive enough to prove that the land cultivation site is the only source of detached oil or to define the areal limits of oil migration.

TABLE 15. RESULTS OF SOIL AND WATER SAMPLE ANALYSES WELLS A, B, C, AND D

Well/ Sample No.	Type of Sample	Depth of Sample		Parameter (in ppm unless otherwise noted)					
				Moisture Content % by wt.	Organic Acid	Total Organic Nitrogen	Total*		
		m	ft				P	Pb	Fe
A 1	Soil	surface			75	834.0	2053	3.0	6900
2	"	0.9	3	11.6	570	552.0	949	4.2	1395
3	"	1.5	5	12.1	420	703.0	1151	3.0	3360
4	"	3.6	12	3.3	60	115.0	1289	2.4	3400
5	"	4.8	16	10.7	990	116.3	1275	5.2	2025
6	"	6.9	20	22.1	60	46.2	1449	1.0	3550
7	"	9.4	31	19.6	60	42.7	375	4.0	3900
8	Water	3.3	11	--	20	36.4	1	0.8	252.5
B 1	Soil	surface		--	--	--	--	--	--
2	"	2.4	8	--	--	--	--	--	--
3	Water	3.0	10	--	70	294.0	9	0.7	100
C 1	Soil	1.0	3	5.1	30	43.4	1458	3.0	2500
2	"	2.1	7	16.4	2304	72.2	249	5.8	3538
3	"	3.0	10	16.8	180	40.6	1824	1.6	3025
4	"	4.5	15	16.9	582	39.2	645	3.0	2835
5	"	5.7	19	16.4	330	48.3	116	3.6	3135
6	Water	2.7	9	--	270	359.0	0	1.0	222.5
D 1	Soil	1.0	3	17.2	420	33.9	1919	5.0	4375
2	"	4.2	14	3.9	60	76.2	1437	2.4	4900
3	Water	2.4	8	--	69	26.6	0	0.7	226.5

*Digested in HNO_3-$HClO_4$. Concentration in μg/g of soil or water as received.

(continued)

TABLE 15 (Continued)

Well/ Sample No.	Type of Sample	Depth of Sample		Parameter				
				Total Extractable Hydrocarbons mg/g	Oil Content mg/g	Oil Fractions, percent		
		m	ft			Paraffin	Aromatic	Polar
A 1	Soil	surface		39.1	32.8	29.7	12.2	57.9
2	"	0.9	3	--	--	--	--	--
3	"	1.5	5	41.1	34.2	27.6	1.3	59.3
4	"	3.6	12	3.0	3.0	26.3	13.1	60.5
5	"	4.8	16	0.1	0.1	13.7	2.2	84.0
6	"	6.9	20	3.7	3.6	28.9	12.2	58.7
7	"	9.4	31	0.3	0.3	24.2	7.8	67.9
8	Water	3.3	11	59.0 mg/ℓ	36.8 mg/ℓ	24.9	10.0	64.1
B 1	Soil	surface		39.1	32.8	29.7	12.2	57.9
2	"	2.4	8	0.1	0.1	17.3	6.6	76.0
3	Water	3.0	10	53.0 mg/ℓ	23.4 mg/ℓ	22.1	7.7	70.1
C 1	Soil	1.0	3	0.2	0.1	7.6	6.2	86.0
2	"	2.1	7	0.2	0.1	27.2	2.0	51.9
3	"	3.0	10	--	--	--	--	--
4	"	4.5	15	51.8	37.1	33.9	9.9	56.2
5	"	5.7	19	0.2	0.1	20.0	12.9	66.8
6	Water	2.7	9	44.8 mg/ℓ	19.8 mg/ℓ	14.1	5.5	80.0
D 1	Soil	1.0	3	0.6	0.2	14.7	17.4	67.8
2	"	4.2	14	51.8	37.1	33.4	9.7	56.2
3	Water	2.4	8	27.2 mg/ℓ	7.2 mg/ℓ	15.5	3.3	81.1

TABLE 16 RESULTS OF SURFACE SOIL/OIL SAMPLE ANALYSIS

Date of Sampling	Parameter				
	Total Extractable Hydrocarbon, mg/g	Oil Content, mg/g	Oil Fraction, Percent		
			Paraffin	Aromatic	Polar
3/19/76	39.1	32.8	29.7	12.2	57.9
4/7/76	42.0	30.7	27.5	9.5	62.9
4/19/76	31.4	27.2	31.5	10.8	57.6
4/21/76	29.0	26.3	26.3	11.7	61.8
5/5/76	34.5	31.6	27.6	11.2	61.1

The concentrations of oil in soil samples taken from the four wells range from less than 0.1 mg/g (at different depths in Wells A, B, and C) to 34.2 mg/g at 1.5 m (5 ft) deep in Well A. Although there are many anomalies, the overall trend shows that the oil content of soil samples decreases with depth in each well. However, the oil content of soil samples taken from as deep as 9.4 m (31 ft) was relatively high: 0.26 mg/g (or 260 ppm).

All water samples contained relatively high oil contents: from 7.16 mg/l at Well D to 36.8 mg/l in Well A. This suggests that oily material is reaching the perched groundwater, although the oil source may not necessarily be the land cultivation site. Analyses of upstream groundwater were not available for comparison. Seawater intrusion probably affects the perched water farther inland than the site, so background water may also contain oil from the site (24). The relative paraffinic, aromatic, and polar oil fractions for oil taken from water samples are close to the fractions taken from soil samples.

Oil may have entered the groundwater by downward migration through the sand, or it may have been leached from the upper soil profile during periods of high seawater intrusion, when the groundwater elevations are near the surface. Also, oil exploration and storage in the vicinity could contribute some of the oil detected in the groundwater sampled.

Field Sampling and Chemical Analyses

Soil and vegetation samples were collected in November 1976 as a part of this study. Surface soil (0 to 30 cm) samples were taken from a treated plot that received oily wastes in September and a control plot which had never received oily wastes. Vegetation samples taken in the area of the soil samples included tall grass (*Distichlis spicata*), golden bush (*Haplopappus ericoides*), ragweed (*Ambrosia chamissonis*), and ice plant (*Carpobrotus edulis*). The soil and plant samples were analyzed, and the results are presented in Tables 17 and 18.

Land cultivation of oily wastes resulted in increases in soil pH, soluble salt content, and levels of total Kjeldahl nitrogen (TKN) and organic carbon in the soil (Table 17). The accumulations of soluble salts (expressed as electrical conductivity or EC) and organic carbon are of particular significance. Salt-sensitive plants could be injured with the elevated salt levels reported for the treated soil. However, the physical and chemical properties of the soil should be improved with buildup of organic matter derived from the oil.

Concentrations of HCl-extractable sodium and water-soluble boron in the oil-treated soil increased dramatically over those in the control soil. These concentrations, however, are not

TABLE 17. CHEMICAL CHARACTERISTICS OF THE CONTROL AND OIL-TREATED SANDY SOIL - SOUTHERN CALIFORNIA

Parameter*	Control	Treated
pH	6.04	7.65
EC, mmhos/cm	0.40	4.46
Oil, %		2.28
TKN, %	0.006	0.079
Org. C, %	0.16	2.53
	- - - - - - - - - ppm - - - - - - - - -	
Ortho-P	410	230
Na	110	280
B	<0.20	2.28
Mn	35.4	55.0
Ni	1.5	2.5
Zn	7.5	40.7
Se	0.022	0.09
Mo	1.3	1.1
Cd	0.14	0.06
Pb	4.2	5.4

*Electrical Conductivity (EC) and B (μg/ml) were measured in the saturation extracts; other elements in ppm (μg/g) were determined in 0.1N HCl extracts.

TABLE 18. CHEMICAL ANALYSIS OF SOME PLANT SPECIES GROWN ON THE CONTROL (C) AND OIL-TREATED (T) SANDY SOIL - SOUTHERN CALIFORNIA

	Tall Grass		Golden Bush		Ragweed		Ice Plant	
Element	C	T	C	T	C	T	C	T
	- - % - -		- - % - -		- - % - -		- - % - -	
N	1.12	1.49	1.57	1.76	2.52	0.87	1.29	0.91
P	0.15	0.16	0.21	0.28	0.32	0.33	0.21	0.21
	- - μg/g - -		- - μg/g - -		- - μg/g - -		- - μg/g - -	
Na	1875	2437	4560	5125	2560	3375	20937	36560
B	28	38	4.4	48	102	96	12	12
Mn	50.5	58	53	83.5	88	95.4	96.7	198
Ni	3.8	5.9	6.9	7.1	6.9	8.5	3.8	2.0
Zn	18.5	30.7	40.1	71.2	101.4	190	40.6	38.2
Se	0.013	<0.013	<0.013	<0.013	0.04	0.125	0.04	0.04
Mo	1.6	4.7	0.75	0.6	1.2	0.71	0.31	<0.1
Cd	0.26	0.62	0.41	0.52	0.05	0.05	0.10	0.21
Pb	5.5	20.3	5.6	12.5	3.12	18.0	3.12	3.28

considered excessively high in terms of plant injury. Boron levels in the treated soil may be beneficial to the vegetation growing at the disposal area since the control soil is deficient in boron.

The oil-treated soil contained significantly higher HCl-extractable manganese, nickel, zinc, selenium, and lead than the control soil.

Plant analyses indicate relatively low nitrogen and phosphorus contents irrespective of oil treatment and plant species (Table 18). In general, land cultivation of oily wastes at this site increased sodium, manganese, zinc, and lead in plant tissues as compared to plants on the control soils. There were also species variations, as shown by the higher manganese concentrations in ragweed and ice plant than in golden bush and tall grass. Ragweed and iceplant accumulated high levels of zinc and manganese, respectively.

Waste Storage

No waste storage facilities are provided at the site, since weather conditions that preclude land cultivation activities occur only a few days each year. The nature of the wastes are such that disposal can be delayed with no adverse effects until weather and soil conditions allow the wastes to be land cultivated.

Equipment Summary

Equipment at the site consists of three track dozers and a disk harrow. Vacuum trucks used to transport oily wastes to the site belong to the oil companies or contract haulers. The dozers are used for mixing the waste into the soil and for site grading. Little use is made of the disk harrow, primarily because of equipment wear and because the track dozers provide adequate mixing. One International Harvester 2025 and two 2D24 dozers are used. Due to the abrasive nature of the oil/sand mix, as indicated by excessive wear to the undercarriage expected life of a dozer is only 6 to 7 yr.

Personnel

The dozer operator is the only full-time (usually 60 hr/wk) employee at the site. In addition to operating the dozer, he performs all necessary equipment maintenance functions. Traffic control is unnecessary since vacuum trucks arrive infrequently throughout the day.

Economic Summary

No overall cost information is available. The operator did indicate that the disk harrow is more costly to operate than the track dozer because of increased equipment wear. The oil/sand mixture causes significant abrasion of all moving parts of the disk harrow since the oily sand tends to stick and act as a grinding compound.

The fee for dumping the oily waste is 3.6¢/l (40¢/bbl). Land lease costs are approximately 25 percent of the gross income. Dozer operation and maintenance costs, including amortization, average $1,500 to $2,000/mo. Personnel costs, including fringe benefits, are about $2,000/mo. No estimate of the cost of utilities at the site (electricity and water) was available, although water purchased from a nearby oil company costs the operator 0.6¢/l (7¢/bbl). The site operator carries $1 million in liability insurance for this site. Table 19 presents a monthly cost summary.

TABLE 19. ECONOMIC SUMMARY -
SOUTHERN CALIFORNIA SITE

Item	Monthly Cost
Operation and maintenance	$2,000
Salary and benefits	2,000
Insurance	400*
Utilities	100*
Land lease	3,000†
Total	$7,500
Unit cost	25¢/bbl†

*Estimated cost.
†Based on 30,000 bbl/mo waste input.

Problems Encountered/Public Response

Until recently, no significant problems or adverse public response had been encountered in over 20 yr of site operation. Within the last year, however, an incident occurred nearby that was totally unrelated to the site but drew public attention to this operation. Since that time, some complaints have been made that odors are emanating from the site that are polluting the area. The operator denies that the site is the source of any odors in the surrounding area. During examinations of the site on more than one occasion, little odor was detected on site, and no odor was detected off site.

Supporting Information

This section presents year-by-year tabulations of total wastes received. The information was obtained from a review of the files of the California Water Quality Control Board (CWQCB), Los Angeles office. These files included Compliance Inspection Reports prepared by the CWQCB. These reports indicate that no adverse effects were noted from the waste dumping activities. A memorandum from the Ventura County Public Works Agnecy was also reviewed, dealing with monitoring performed at the site in 1974 in support of an environmental impact report. This monitoring indicates that little migration of hydrocarbons was in evidence at the site at the time of the investigation.

Tabulations of Total Wastes--

Yearly Waste Inputs

Year	Total Input - m^3	Total Input - bbl
1976	82,970	521,910
1975	65,050	409,180
1974	69,180	435,225
1973	53,195	334,630
1972	48,155	302,935
1971	43,420	273,120
1970	25,865	162,690
1969	27,185	170,995
1968	15,915	100,100
1967	18,885	118,800
1966	18,775	118,100
1965	17,565	110,500
1964	10,890	68,500
1963	8,535	53,700
1962	6,485	40,800
1961	4,610	29,000
1960	15,470	97,300
Total	532,150	3,347,485

ILLINOIS

Summary

Since July 1973, Company X has been operating a combined solid waste and industrial liquid waste disposal site in northern Illinois. The site receives residential refuse, industrial wastewaters and sludges from ten large industries in the area, and some septic tank waste.

Over a year, the monthly input of industrial and septic tank wastes averages approximately 3,030 m^3 (800,500 gal), ranging from a low of 0 to a high of about 5,800 m^3 (0 to 1.5 MG). Approximately 70 percent of this waste stream, or an average of 2,100 m^3/mo (555,000 gal), is industrial wastewater; the remainder is septic tank waste. In addition, an average of 1,070 m^3 (1,400 yd^3) of refuse is disposed of daily in the sanitary landfill area on the site.

Two disposal procedures are used at this site: landfilling and land cultivation. Landfilling is used for the portion of the industrial waste with a relatively high glycerine content. Mixing this waste with other industrial wastes creates pumping problems; therefore, it is placed in the landfill with the refuse. Landfilling is performed at a ratio of about 0.05 m^3 of wastewater/m^3 of refuse (10 gal/yd^3). Most of the industrial wastewater and sludge, along with the septic tank waste, is land cultivated. Land cultivation is conducted on 45 ha (110 ac) of land by surface spreading and disking.

History of Land Cultivation Activity

Until early 1973, the land was a farm. At that time, it was purchased as a disposal site, with zoning for the entire 63 ha (156 ac) changed to allow a sanitary landfill. Shortly thereafter, company X assumed operation of the site from the previous owner. It was assumed that the site had an expected life of 25 yr.

Land cultivation of septic tank and industrial sludges has been practiced at the site since the beginning of disposal activities. Through 1976, the wastes were injected about 10 cm (4 in) below the soil surface, using two 8.5-m^3 (2,250-gal) "honey wagons" equipped with rear plow and injector mechanisms. Two International Harvester tractors were used to pull the honey wagons. After injection of sludge, the fields were disked to facilitate mixing with the soil. In 1977, this application method was changed to surface spreading to enhance evaporation, followed by disking.

Site Description

The site is located near Illinois State Highway 53, as shown in Figure 16. It is owned and operated by company X.

Site Area--

The site covers a total of 63 ha (156 ha) (Figure 17). The area is divided into six land cultivation fields - five of approximately 8 ha (20 ac) and one of 4 ha (10 ac) - and the landfill, which covers about 16 ha (40 ac). The remainder of the land is used for two sludge holding basins, roads, and buildings. Selection of the field to be used is based on a rotating schedule, modified, if necessary, to ensure that all wastes applied to a given field are compatible.

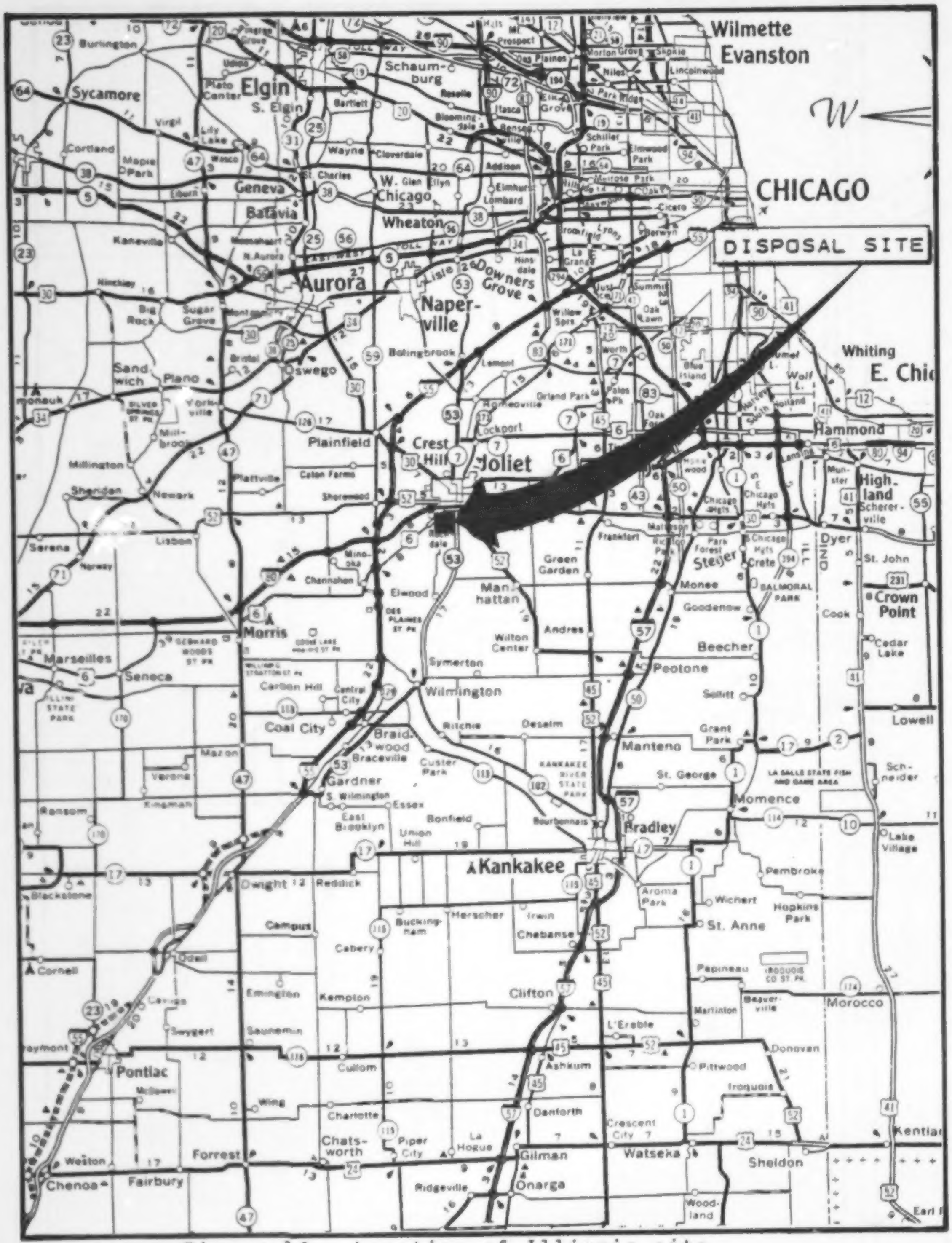
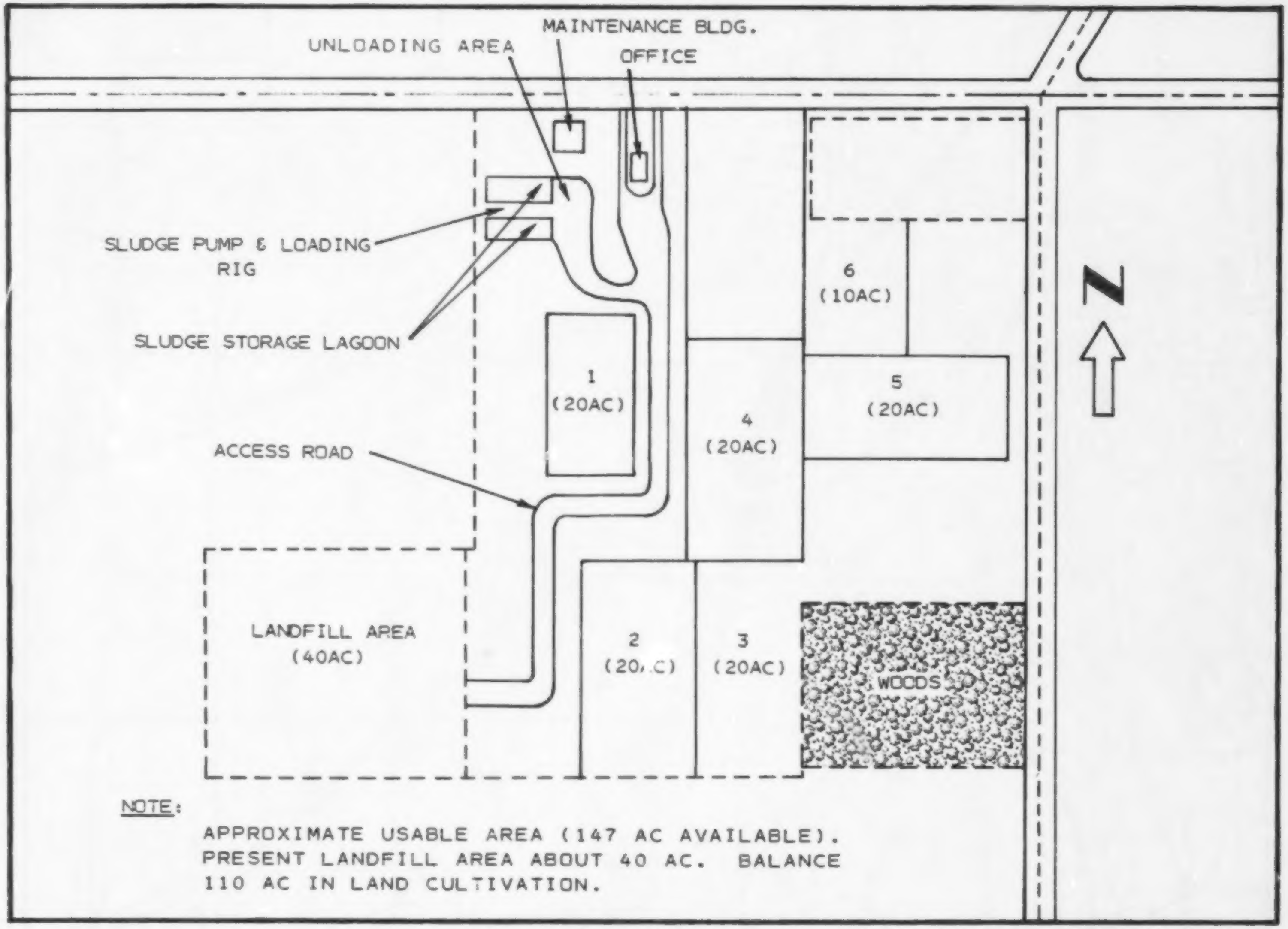

DISPOSAL SITE
W
CHICAGO
Wilmette
Evanston
Elgin
Sycamore
Schaumburg
Geneva
Batavia
Aurora
Wheaton
Downers Grove
Naperville
Oswego
Plainfield
Crest Hill
Joliet
Lockport
Romeoville
Bolingbrook
Hammond
E. Chi
Whiting
Highland
Steger
Crete
Monee
Peotone
Beecher
Manteno
Momence
Bradley
Kankakee
Wilmington
Braidwood
Coal City
Morris
Marseilles
Seneca
Dwight
Pontiac
Chenoa
Fairbury
Forrest
Chatsworth
Gilman
Onarga
Watseka
Sheldon
Clifton
Chebanse
Ashkum
Crown Point
Lowell
Manhattan
Elwood
Channahon
Minooka
Morocco
St. Anne
Momence
Yorkville
Plano
Sandwich

Figure 16. Location of Illinois site.


MAINTENANCE BLDG.
UNLOADING AREA
OFFICE
SLUDGE PUMP & LOADING RIG
SLUDGE STORAGE LAGOON
ACCESS ROAD
1 (20AC)
2 (20AC)
3 (20AC)
4 (20AC)
5 (20AC)
6 (10AC)
WOODS
LANDFILL AREA (40AC)
N

NOTE:

APPROXIMATE USABLE AREA (147 AC AVAILABLE). PRESENT LANDFILL AREA ABOUT 40 AC. BALANCE 110 AC IN LAND CULTIVATION.

Figure 17. Site layout.

Physical Features--

Terrain throughout the region is typical of much of the Midwest. The land is relatively flat, with a few gently rolling areas. The highest area is on the eastern side of the site, sloping slightly to the west. All surface and groundwater drainage is toward the Des Plaines River, which lies approximately 550 m (1,800 ft) west of the disposal site. Depth to groundwater is about 10 m (32 ft). Large clay berms have been constructed around the entire site to control surface runoff. These berms are sized so that, at finished grades, 0.6 m (2 ft) of freeboard will remain.

The access road enters the site from the north. Incoming trucks check in at the office (Figure 17) and then proceed to the holding basins at the northwest corner of the site, where their sludge loads are emptied. An interior access road extends to the landfill property at the southwest corner. This road lies above the level of the surrounding land cultivation fields, thereby serving as an additional berm to control and direct on-site drainage.

Since the site is devoted to sludge disposal, on-site vegetation is quite sparse. Most of the area is bare soil, with occasional patches of weeds and low brush. A small wooded area lies to the southeast. Land to the east and south of the site is still being used for agriculture.

Climate--

The climate of the area is typically midwestern, with hot summers, dry cool falls, cold winters, and wet windy springs. Sludge cultivation does not take place during the winter months (November through February), as the ground freezes and operators want to avoid runoff during spring thaws. Table 20 presents climatic data.

Soil Types--

The soils at this site are comprised of Huntsville loam, Lorenzo silt loam, and Romeo silt loam. Huntsville loam, the predominant soil in the area, is a dark, moderately well-oxidized soil formed in medium-textured alluvial sediments 120 or more centimeters thick. The surface 0 to 25 cm (0 to 10 in) is black to very dark brown friable loam to gritty silt loam, neutral and high in organic matter. The subsurface 25 to 102 cm (10 to 40 in) is very dark grayish brown to yellowish brown silty clay loam, neutral to slightly acid. Drainage decreases drastically at lower depths as evidenced by the presence of reddish brown mottles.

Native vegetation is mostly prairie, often with scattered trees or brush. Pasture is the best use for most areas with Huntsville loam. Drainage may be needed for satisfactory grain farming.

TABLE 20. SUMMARY OF CLIMATOLOGICAL DATA: CHICAGO, ILLINOIS

Month	Precipitation	Temperature		Winds	
	Normal	Maximum	Minimum	Mean Hourly Speed	Prevailing Direction
January	4.7 cm (1.9 in)	1°C (33°F)	-7°C (19°F)	18.3 kmph (11.4 mph)	W
February	4.1 (1.6)	2 (35)	-6 (21)	18.7 (11.6)	W
March	7.0 (2.7)	6 (44)	-2 (29)	10.0 (11.8)	W
April	7.7 (3.0)	14 (57)	5 (40)	18.8 (11.7)	W
May	9.5 (3.7)	21 (69)	10 (51)	16.7 (10.4)	SSW
June	10.3 (4.1)	26 (80)	16 (62)	14.8 (9.2)	SW
July	8.6 (3.4)	29 (84)	20 (67)	13.2 (8.2)	SW
August	8.0 (3.2)	28 (82)	19 (66)	12.9 (8.0)	SW
September	6.9 (2.7)	24 (75)	14 (57)	14.3 (8.9)	S
October	7.1 (2.8)	17 (63)	8 (47)	15.8 (9.8)	S
November	5.6 (2.2)	8 (47)	0 (32)	18.3 (11.4)	SSW
December	4.8 (1.9)	2 (36)	-2(29)	18.0 (11.2)	W
Year	84.3 cm (33.2 in)	15 (59)	6 (43)	16.6 (10.3)	W

State and Local Regulations

The state of Illinois regulates the site, although there are no specific regulations dealing with land cultivation. The state has two basic requirements for site operation: first, state permits are required for each waste being cultivated; second, groundwater monitoring is required.

Waste Characteristics

Sludges cultivated at the site are received from a variety of sources. Major waste types received include:

- Sulfate wash water and cooling water from a natural gas utility
- SO_2 stack scrubber blowdown
- Oil waste residue
- Sulfate water and vegetable oils
- API separator sludge
- Soap manufacturing rendering waste, grease skimmings, and glycerine pitch
- Septic tank sludge.

In addition, minimal amounts of industrial wastewater and sludge are received from several relatively small local industries.

Most of the waste has not received any pretreatment. Approximately 284 m^3 (75,000 gal) per day is land cultivated during the spring, summer, and fall seasons. Most of the soap manufacturing waste is disposed of, with the refuse, in the landfill. Most of the remainder of the sludge and wastewater is land cultivated.

This site is a commercial operation, disposing of wastes generated by others for a fee. Because of this, the site operator cannot release specific characteristics of the various wastes.

Waste Storage/Transportation

All sludges and wastewaters are transported from the point of generation to the disposal site in tank trucks. Refuse is delivered in commercial packer trucks, and debris in open body vehicles. Solid wastes are immediately landfilled. Liquids are either dumped directly in with the refuse (all wastes which are not readily biodegradable are so handled) or are deposited in one of two storage lagoons (Figure 17). Each lagoon is an earthen basin with compacted clay bottom and 4,920-m^3 (1.3-MG) capacity. Lagoon dimensions are 89 m long x 42 m wide x 4.6 m deep (292 ft long x 137 ft wide x 15 ft deep). The very heavy clay soil impedes percolation from the basins).

Figure 18 shows the south storage lagoon. In the center background is the sludge pump, to the left of which is the sludge loading rig. Figure 19 pictures the north lagoon, where waste containing glycerine was previously placed. When this glycerine waste was mixed with oily wastes already in the lagoon, pumping problems resulted because of the thick, solid crust on the surface.

Waste Application

Land cultivation operations commence when the ground thaws in the spring. Sludge is pumped from the lagoons into one of the three 8.5-m^3 (2,250-gal) honey wagons equipped with rear attached plow mechanisms (see Figure 20). These tank trailers are pulled by one of two International Harvester 125-hp tractors (Figure 21), one with dual rear tires and the other with single rear tires. The waste is then spread on the soil surface. Figure 22 shows a field a few minutes after the sludge has been spread. Pools of sludge stand in the area directly below the tank trailer spreading nozzle, which can be seen at the center rear of the tank in Figure 20. The fields are disked by one of the tractors after sludge application. An International 250 (165-hp) tracked vehicle is used during muddy conditions. Figure 21 shows the disk used.

When applying sludge, the empty tank trailer is driven to the loading rig shown in Figure 18. The driver positions the trailer under a hose in the rig, then opens a port on the trailer top and starts the sludge pump. When the trailer is filled, the pump is stopped, the port closed, and the tractor-trailer proceeds to the field being used.

Six separate fields constitute the total 45 ha (110 ac) currently utilized for land cultivation. Wastewaters are applied on a rotating basis. During a typical 9-hr day, several loads, of 8.5 m^3 (2,250 gal) each, are spread on a single 8-ha (20-ac) field. Total waste loading, between diskings, averages approximately 60 m^3/ha (6,250 gal/ac). If rain does not interfere, sludge is applied at the above rate to a field during one day. The field stands idle to dry the following day, and is then disked the next day. Sludge can be reapplied to the field the day after disking; thus each field can receive sludge every three days.

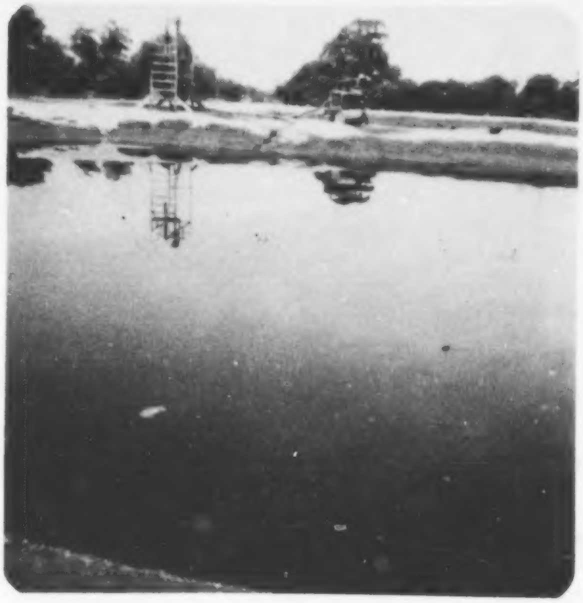


Figure 18. South sludge holding lagoon with pump and loading rig in background.

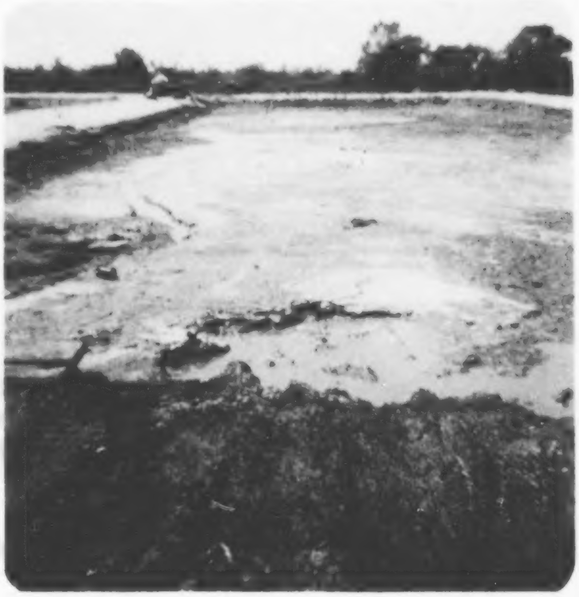


Figure 19. North sludge holding lagoon showing effect of glycerine wastes.

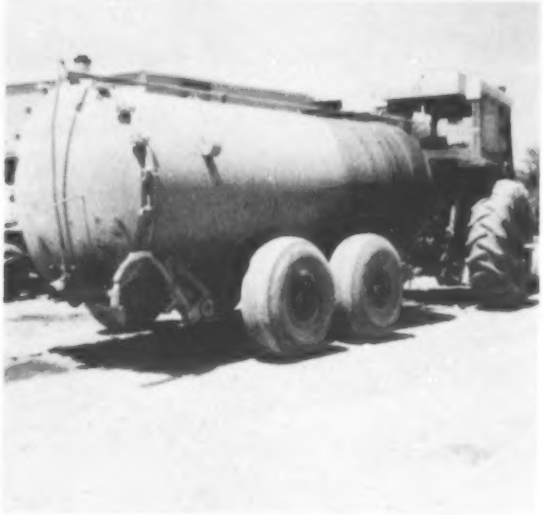


Figure 20. Sludge spreading tank wagon - Illinois site.

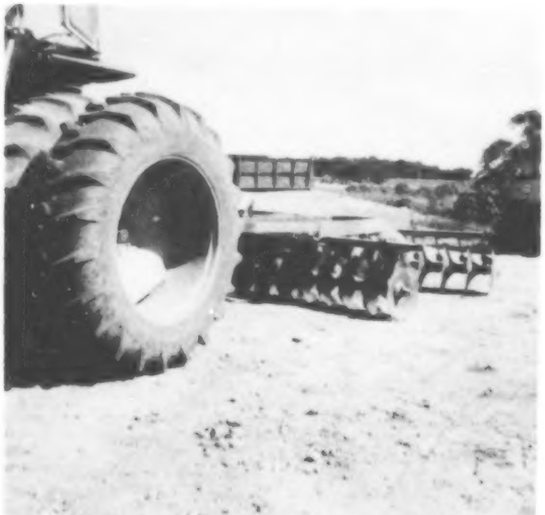


Figure 21. Tractor and disc used to mix sludge into soil - Illinois site.

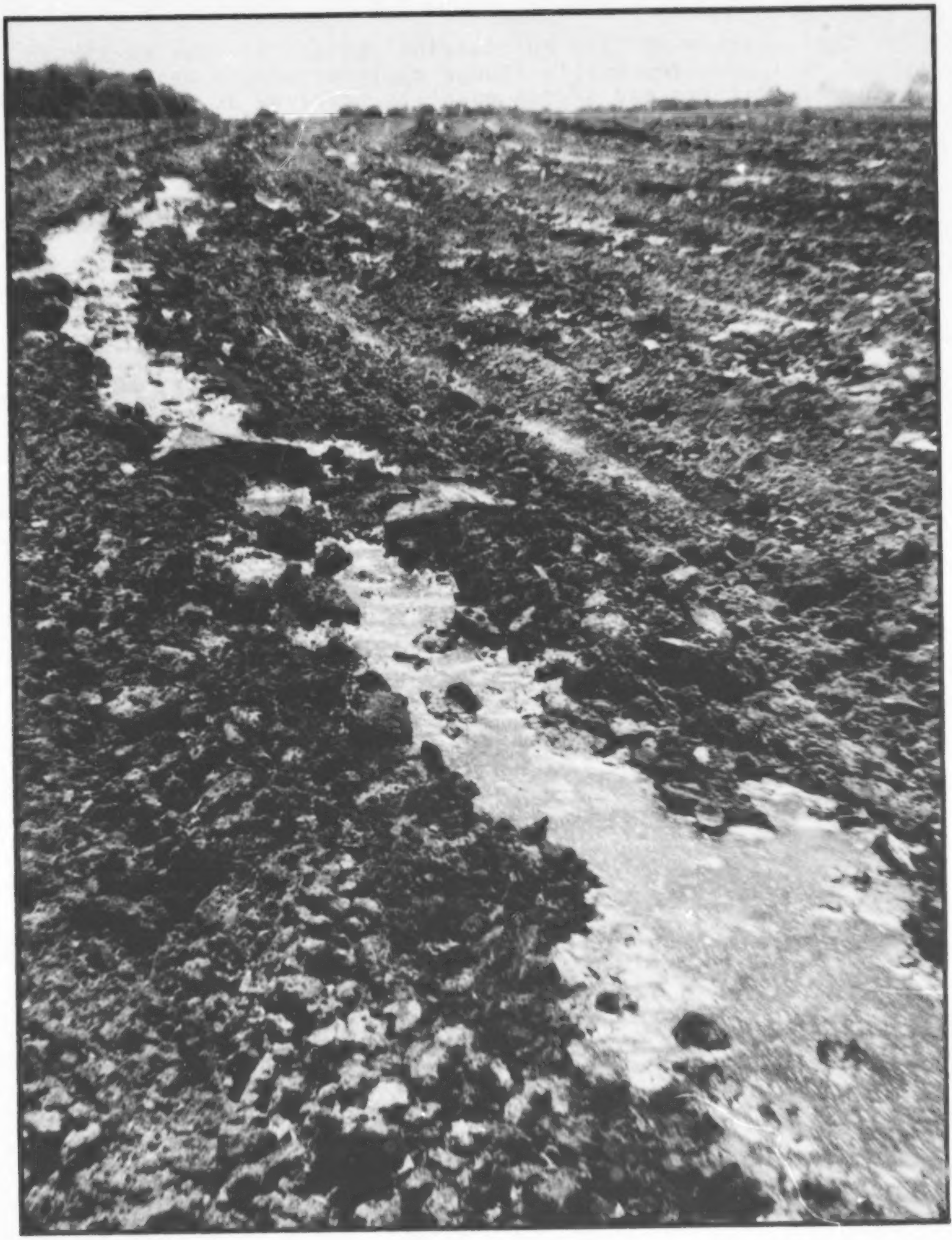


Figure 22. Illinois field shortly after sludge spreading.

During the 8-mo land cultivation season, six-day weeks are normal, allowing two weekly sludge applications on each field. Weather conditions and sludge quantity received do not allow this application rate to exist for all six fields for the entire 8 mo, so the annual loading rate averages about 830 m^3/ha (86,700 gal/ac).

No fertilizers or other chemicals are added to the soil, and no crops are grown. The operation is totally oriented toward disposal.

Environmental Factors

The state of Illinois requires that groundwater quality be monitored. To meet this requirement, four 5-cm (2-in) diameter monitoring wells are located at the corners of the property. The wells extend approximately 10 m (32 ft) through the deep clay layer into the gravel aquifer.

Two of the monitoring wells have been consistently dry. Water from the other two wells is analyzed quarterly for TDS, pH, Fe, Cl, and EC, with results reported to the state. Analysis of the water samples is performed in the company's laboratory. No surface water or soil monitoring is performed.

To date, no significant adverse environmental impacts have been found. When the site was toured, some odors were noted, especially near the sludge storage lagoons. The primary odor noted was that of oil from the oily wastes. This odor was also noticeable in the field where sludge was being spread. However, the odors were very low level and were not detected off site.

Equipment and Personnel Summary

For the land cultivation activities at the site, the following equipment is used:

- Three 8.5-m^3 (2,250-gal) honey wagon tank trailers (Figure 20)
- Two International Harvester (IH) Model 1066 (125-hp) farm tractors (Figures 20 and 21)
- One IH Model 250 (165-hp) track dozer
- One standard IH farm disk (Figure 21)
- One sludge pump and loading rig (Figure 18).

Two and one-half men (i.e. two employed full-time and one part-time) are assigned to the land cultivation activities. Administrative and maintenance personnel serve both the land cultivation and landfill aspects of the operation. No information was provided regarding time allocation of these people to the land cultivation effort.

Economic Summary

Activities at this site are a commercial disposal operation. Cost information is considered to be proprietary and is closely guarded. Some basic cost estimates were obtained and are presented in Table 21. Disposal fees to customers normally range from $\$3.96/m^3$ to $\$8.72/m^3$ (1.5¢/gal to 3.3¢/gal), dependent on waste type. Higher fees are charged in emergency situations.

TABLE 21. COST SUMMARY, ILLINOIS SITE

Item	Capital Cost	Year Purchased	Annual O&M Cost
• Sludge storage lagoons	$16,000	1975*	$ 2,000
• Sludge spreading			
- IH 1066 tractor	16,000	1973	--
- IH 1066 tractor	8,000	1974	--
- IH 1466 tractor (leased)	--	--	1,200
- 3 "honey wagons"	20,000	1975	--
- IH 250 track dozer	35,000	1976	--
- IH disk	2,200	1975	--
- 2 1/2 workers (including fringe benefits)	--	--	37,500

*Year constructed

Some consideration has been given recently to expansion of the site. Exploratory talks were held with adjacent land owners, which proved unfruitful due to exceptionally high prices asked for the land, on the order of $62,000/ha ($25,000/ac). These prices reflect the possible effects of expanding profitable commercial operations located in mixed agricultural/industrial areas.

Planned Final Site Use

Final site use after closure is intended to be either agricultural or commercial. At the current rate of loading, about 20 yr remain before soil loading of contaminants would require a cessation of land cultivation. Consideration is being given to prolonging site life by stripping the upper 25 to 30 cm (10 to

12 in) of soil when it becomes fully loaded. This stripped soil would be placed in the landfill, and would extend the life of the land cultivation fields.

Public Response and Problems Encountered

There has been very little public response, positive or negative, to operations at this site. The area is basically partially industrialized farmland, with farmers being the only nearby residents.

As a public relations gesture, about five tours are conducted annually for various environmental groups and school classes.

The only significant problems are connected with the storage lagoons. Tank truck drivers often did not get discharge hoses deep enough into the lagoon, which caused severe erosion of one bank. This was solved by the installation of a 60-cm (24-in) culvert into which drivers place their discharge hoses. The other problem is the mixing of oily and glycerine wastes, previously discussed. This is being solved by segregating the glycerine waste.

RHODE ISLAND

Summary

A Rhode Island chemical manufacturing plant utilizes both landfilling and land cultivation to dispose of primary and secondary (activated) wastewater treatment sludge. The chemical plant produces a variety of dyes, dye intermediates, pigments, and ethical pharmaceuticals with batch production operations. Thus, sludge composition varies substantially from day to day.

The sludge is applied to fields of a nearby turf farm during the interval between turf stripping and reseeding. The sludge is applied at a rate of approximately 117 m^3/ha (12,000 gal/ac) per application. Either one or two applications are made, depending on the farm's seeding schedule. When sod is not being stripped and no cleared fields are available, the sludge is landfilled.

Sod production requires the removal of topsoil from the fields. Thus, the turf farm is interested in land cultivation to obtain the benefits of the sludge as a soil conditioner. In addition, the sludge supplies some nutrients, principally nitrogen in the form of ammonia, and helps to maintain the soil pH of the fields in the desired range of 6.5 to 6.7.

Both preliminary greenhouse experiments and 2 yr of full-scale field experience indicate that use of the secondary and primary sludge has some beneficial and no apparent detrimental effects on soil fertility and turf grass production.

History of Land Cultivation Activities

The sludge that is land cultivated at this site is generated at an industrial waste treatment plant which began operation on April 15, 1974. Sludge generated from April 19, 1974, to May 19, 1975, was disposed of exclusively by landfilling. In May 1975, land cultivation activities were initiated at a nearby turf farm. In the months of May and August 1975, approximately 1,500 m^3 (400,000 gal) of sludge were land cultivated. Arrangements were subsequently made to begin land cultivation in the following spring at a different turf farm.

During the late spring and summer of 1976, approximately 3,400 m^3 (900,000 gal) of sludge were disposed of by land cultivation. Land cultivation activities concentrated on three separate fields with a total area of approximately 16 ha (40 ac). The annual loading rate on these fields averaged 212 m^3/ha (22,500 gal/ac).

Since turf is grown in an 18-mo to 2-yr cycle and land cultivation of sludge only occurs between the turf harvesting and reseeding of the field, land cultivation activities in 1977 will be conducted on areas different from those used in 1976. Plans for 1977 are to increase the acreage used and the quantity of sludge land cultivated. The specific fields to be used in 1977 have yet to be identified.

Site Description

This study site is located in Rhode Island, approximately 33 km (20 mi) from Providence. The 160-ha (400-ac) site is shown in Figure 23. The site is owned and operated by a turf farm, which hopes to benefit from the organic amendment and pH stabilization properties of the sludge.

The waste source manufactures approximately 350 different organic chemicals. The wastewater generated by production processes is treated in an on-site, activated sludge treatment system, and the resulting waste sludge is disposed either by landfilling or land cultivation, with the majority of the sludge being landfilled.

Topography and Soils--

The topography of the sludge-treated fields is nearly level, with some gently sloping (less than three percent) rises or depressions. The fields drain to the south into an unnamed stream; but since the topography is so level, substantial overland flow normally occurs only during periods of very heavy

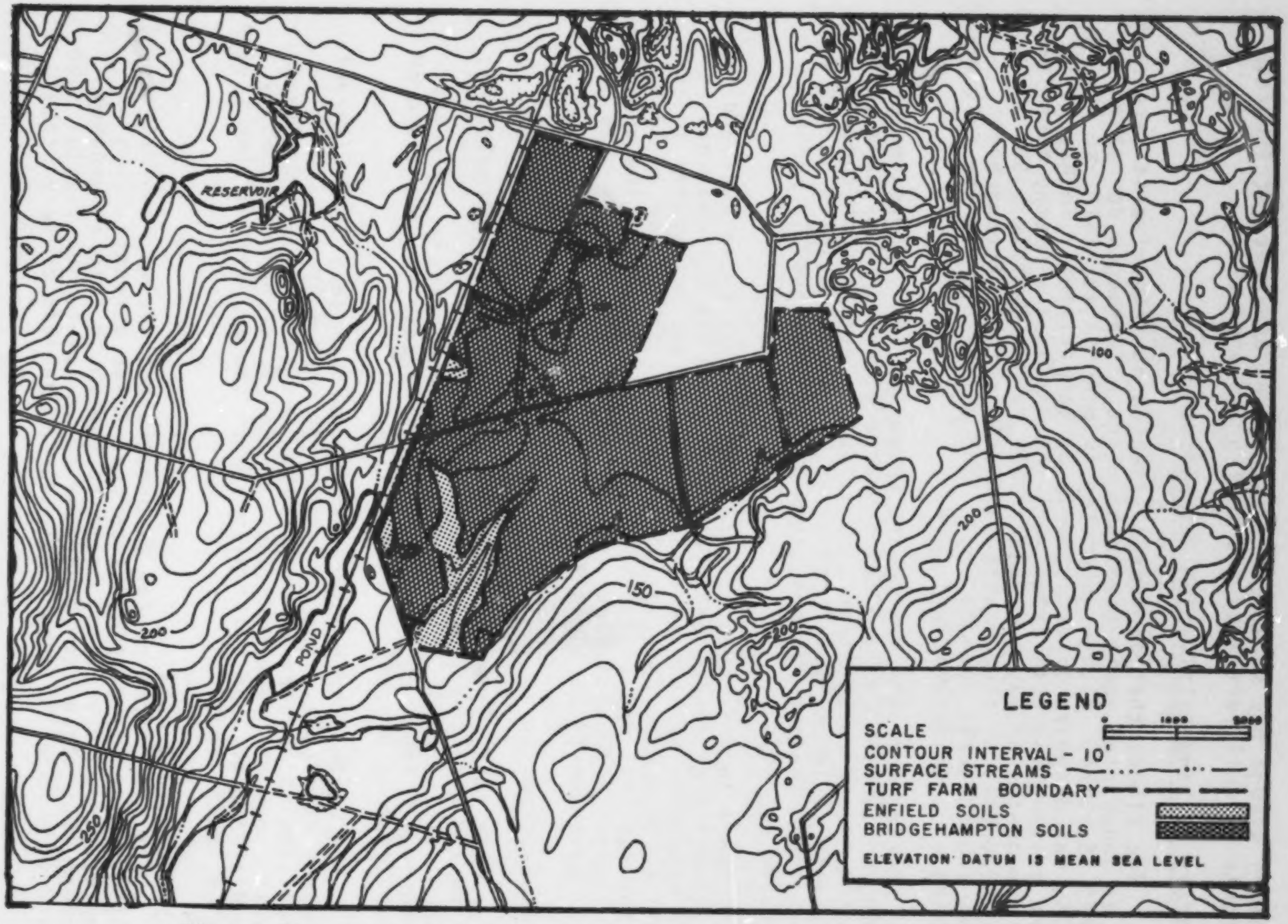

RESERVOIR
POND
100
150
200
250
LEGEND
SCALE
0
1000
2000
CONTOUR INTERVAL - 10'
SURFACE STREAMS
TURF FARM BOUNDARY
ENFIELD SOILS
BRIDGEHAMPTON SOILS
ELEVATION DATUM IS MEAN SEA LEVEL

Figure 23. Rhode Island case study site: topography and soils.

rainfall. The vegetation on the fields is turf grass, the commercial product of the turf farm.

An examination of Figure 23 shows that, though the treated fields are nearly level, they are located in an area of moderately hilly terrain. Outwash terraces, common in the area, have soils that are normally classified in the Bridgehampton and/or the Enfield series (27).

Bridgehampton soils are strongly acidic, well drained to moderately well drained silt loam (27). Surface drainage may be slow or rapid, depending on the slope and soil cover. Internal drainage and permeability in the upper sequum are moderate. The lower sequum may be water-logged in winter, early spring, and after heavy rains because of the strongly contrasting textures in the lower sequum and the substratum.

The Enfield soils are strongly acidic, well drained, nearly level to undulating silt loam developed in a stratified glacial drift (27). Available moisture is high in the solum but low in the substratum, making irrigation necessary for some crops. In addition, adequate applications of fertilizers and lime are required for crop production.

Information on the subsurface geology at the disposal site is provided by boring logs recorded during the installation of a 16.5-m (55-ft), 1.1-m^3/min (300-gal/min), groundwater well used to irrigate the turf grass. The boring logs indicate that sand and gravel were found from 0 to 3 m (0 to 10 ft); medium gravel from 3 to 6 m (10 to 20 ft); hardpan and silt from 6 to 9 m (20 to 30 ft); medium sand from 10 to 12 m (30 to 36 ft); sand and gravel from 12 to 15 m (36 to 50 ft); and fine sand from 15 to 17 m (50 to 56 ft).

Climate--

Climatic data are presented in Table 22. In winter, the temperatures are modified considerably, and many of the major storms drop precipitation in the form of rain rather than snow. The temperature for the entire year averages around 10°C (50°F), ranging from a low of 8.3°C (47°F) to a high of 12.2°C (54°F). January and February are the coldest months, with a mean temperature of about -2°C (29°F), while July is the hottest, with a mean close to 23°C (73°F). Temperatures below -18°C (0°F) in winter seldom occur, averaging less than two days in any month. The annual average precipitation is approximately 109 cm (43 in).

Surface and Groundwater--

The surface water boundary of the river basin passes through the northwest corner of the site, and the boundary of the groundwater aquifer passes nearly through the middle of the site (Figure 24). Based on measurements made in August 1959, depth to groundwater ranges from about 6 m (20 ft) on the south edge of

TABLE 22. HISTORICAL CLIMATIC DATA FOR PROVIDENCE, RHODE ISLAND

	Mean temperature °C (°F)		Normal precipitation	Mean wind speed	Prevailing
Month	Maximum	Minimum	cm (in)	kmph (mph)	wind direction
January	2 (36)	-6 (21)	8.9 (3.5)	18.5 (11.5)	NW
February	3 (38)	-6 (21)	8.8 (3.4)	19.1 (11.9)	NNW
March	7 (45)	-2 (29)	10.1 (4.0)	20.0 (12.4)	WNW
April	14 (57)	3 (38)	9.4 (3.7)	20.1 (12.5)	SW
May	19 (67)	8 (47)	8.9 (3.5)	17.9 (11.1)	S
June	25 (76)	14 (56)	6.7 (2.6)	16.2 (10.1)	SW
July	27 (81)	17 (63)	7.2 (2.8)	15.3 (9.5)	SW
August	27 (80)	16 (61)	9.9 (3.9)	15.3 (9.5)	SSW
September	23 (73)	12 (54)	8.3 (3.3)	15.4 (9.6)	SW
October	18 (64)	6 (43)	8.3 (3.3)	15.6 (9.7)	NW
November	11 (52)	1 (35)	11.5 (4.5)	17.1 (10.6)	SW
December	4 (40)	-5 (23)	10.5 (4.1)	17.7 (11.0)	WNW
Yearly	15 (59)	5 (41)	108.6 (42.8)	17.4 (10.8)	SW

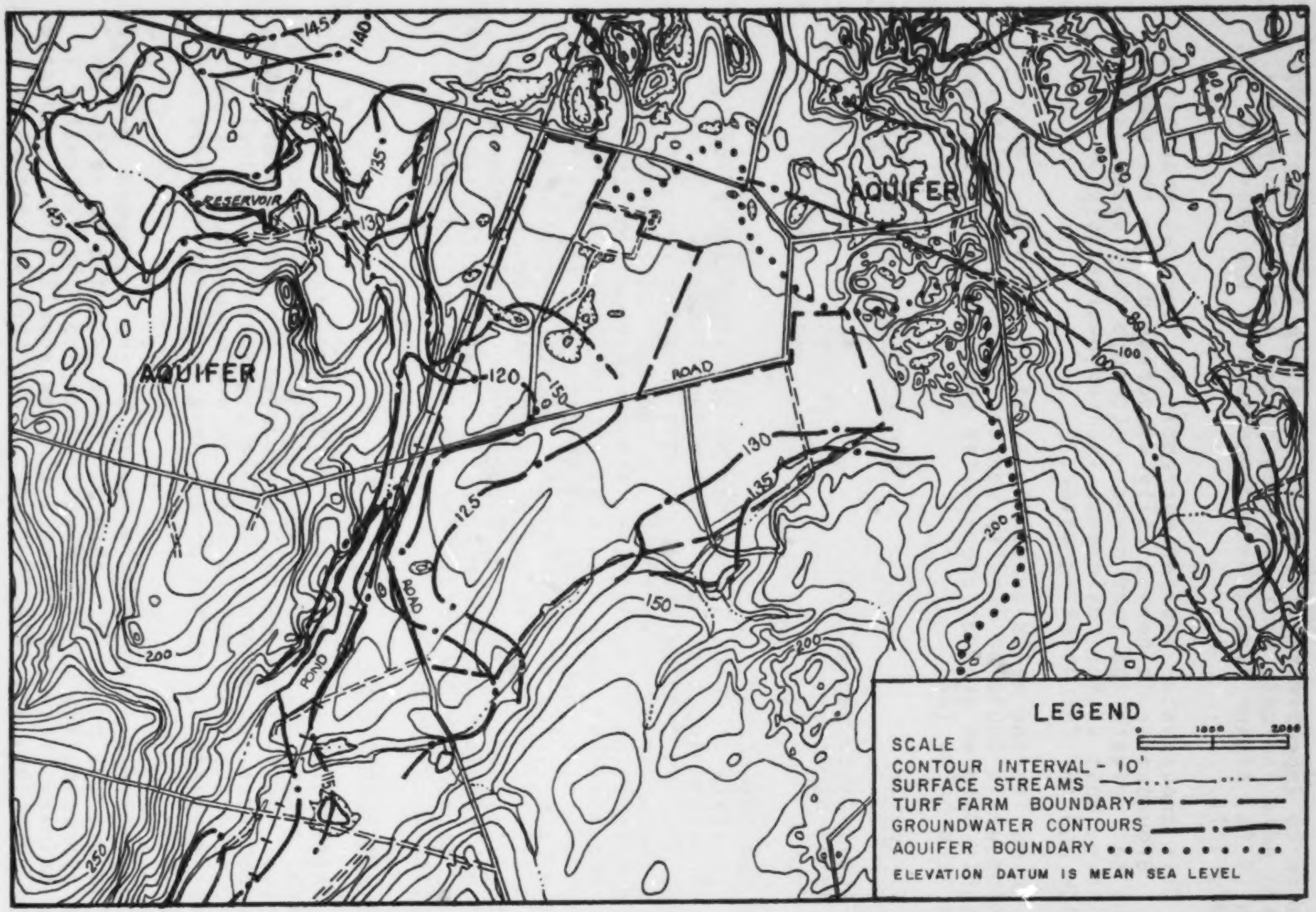

AQUIFER
AQUIFER
RESERVOIR
POND
ROAD
ROAD
145
140
135
130
120
150
125
130
135
115
150
200
200
200
250
100
80
LEGEND
SCALE
0
1000
2000
CONTOUR INTERVAL - 10'
SURFACE STREAMS
TURF FARM BOUNDARY
GROUNDWATER CONTOURS
AQUIFER BOUNDARY
ELEVATION DATUM IS MEAN SEA LEVEL

Figure 24. Rhode Island case study site: aquifer boundary and groundwater elevations.

the site to approximately 10 m (30 ft) along the northern edge. Related data indicate that the groundwater table is approximately 1.5 m (5 ft) higher during wetter portions of the year (28, 29, 30, 31, 32).

This groundwater aquifer currently has several productive uses. Groundwater is periodically withdrawn during the summer months to irrigate the turf grass. Although city water is available, most of the residences located nearby rely on the shallow aquifer for drinking water.

No monitoring wells currently exist at the site. However, existing wells could be used to monitor groundwater quality. Available data on ambient groundwater quality for the site are summarized below (28):

Parameter	Concentration (ppm)
Total dissolved solids	45
Total hardness	15
Iron	0.9

State Regulations--

The state of Rhode Island has no specific regulations or guidelines dealing with land cultivation of wastes. Those responsible for land cultivation activities are required to inform the state as to where they dispose of their wastes. Before initiation of activities, the operator of the chemical plant provided the state with a waste profile and the results of preliminary experiments conducted to determine the feasibility of land cultivation of these wastes. State approval for the land cultivation operation was received; however, no formal permit was issued. The State Department of Health promulgated emergency regulations in December 1977 that require the chemical company to monitor the site. The monitoring method will be established by the state.

Waste Characteristics

This site's land-cultivated wastes are generated by a chemical plant that produces approximately 350 different chemical products. Most of the chemicals produced are dye intermediates, dispersed dyes and pigments, organic pigments, and ethical pharmaceuticals. All of the products are manufactured in batch process operations, and the product mix is different every day of the year.

Wastewaters produced as a result of the production processes have an average pH of less than 1. Lime is added to raise the pH to approximately 7. After neutralization, the wastewater is given primary treatment followed by flow equalization, activated sludge aeration, and chlorination. It is then discharged to an adjacent river. Sludge removed during primary and secondary clarification is discharged into a 19,000-m^3 (0.5 x 10^6-gal) concrete holding basin.

Sludge from the basin is pumped at approximately 5 to 7 percent solids content and disposed of either by landfilling or land cultivation. The quantities of sludge generated, percent solids as disposed, and method of disposal for the years since the treatment plant became operable in April 1974 are summarized below:

Year	Sludge Generated and Method of Disposal (1,000 m^3) Landfill	Land Cultivation	Average of Solids Disposed (%)
1974	35	0	4
1975	20	1.5	5
1976	34	3.4	7

Regardless of the method of disposal, the sludge is hauled from the treatment plant by a contractor using either a 19- or 23-m^3 (5,000- or 6,000-gal) tank truck. The distance from the treatment plant to the land cultivation site is approximately 20 km (12 mi), and the contractor charged \$0.004 per l (\$0.015 per gal) in 1977 for sludge hauling and spreading. This cost rose to \$0.007 per l (\$0.025 per gal) in 1978.

Typical sludge characteristics are shown below:

Parameter	Concentration (ppm at 5% solids)
Total P	33
Total N	213
Fe	0.28
Ca	370
Zn	0.35
Mn	<0.10
Cu	<0.10
pH	8-9

However, it should be noted that the characteristics vary considerably depending on the production mix. No information is available on the intermediate or final degradation products resulting from land cultivation of the sludge.

Waste Application

Sludge is land cultivated at the turf farm in the interval between turf harvesting and subsequent reseeding of the fields. After the turf has been cut and stripped from the fields, sludge is spread from the same truck used to haul it from the wastewater treatment facility. The truck is equipped with a spreader bar approximately 3 m (9 ft) wide, allowing the sludge to drain from the truck as it is driven across the field.

To spread the sludge, the driver opens a valve on the rear of the truck. This allows sludge to flow from the spread bar (Figure 25). The sludge is spread at a rate of approximately 117 m^3/ha (12,000 gal/ac) per application as the truck slowly drives across the field (Figure 26). Generally, the sludge dries rather quickly, as indicated in Figure 27.

Following application of the sludge, the fields are normally cultivated to a depth of 15 to 30 cm (6 to 8 in) within a week. If weather and reseeding schedules permit, sludge is applied a second time before the fields are reseeded. This second sludge application is also cultivated into the soil as in the first application. Since turf matures in approximately 18 mo and fall seeding is preferred, the turf cycle is normally two years. Sludge application and cultivation only occurs between crops, and the maximum sludge application rate is normally 234 m^3/ha (24,000 gal/ac). Preliminary laboratory experiments indicated that application rates up to 1,420 m^3/ha (150,000 gal/ac) had no detrimental effects on the turf grass germination or growth.

Records have been kept on the total quantity of sludge land cultivated. However, records of the quantity of sludge disposed on particular fields are not available. It is estimated that the sludge loading rate for the three sludge-treated fields shown in Figure 29 (total area of approximately 10 ha (40 ac)) has been approximately equal and has averaged 210 m^3/ha (22,500 gal/ac).

Although the sludge is a significant source of nutrients, it does not provide adequate nutrients for maximum sod growth. Fertilizer (27-6-4) is usually applied three to five times per year to supply approximately 90 kg (200 lb) of nitrogen. The fields are limed, as needed, to maintain pH above 6. In addition, preemergent crabgrass herbicides are often used.

Environmental Factors

No monitoring activities have been conducted for the land cultivation activities at this site through 1977. Preliminary greenhouse experiments indicate that the sludge applications

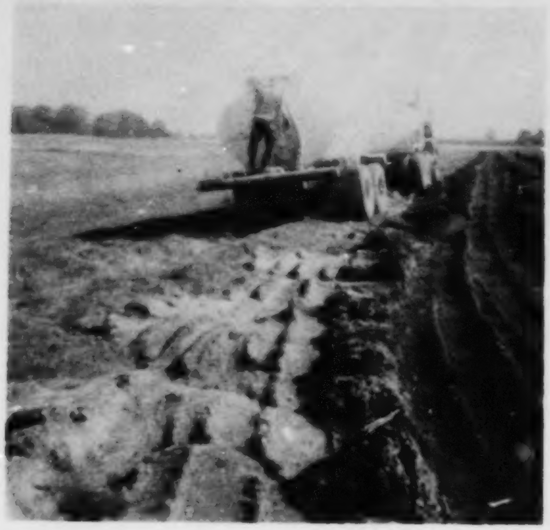


Figure 25. Driver opening valve on tank truck.

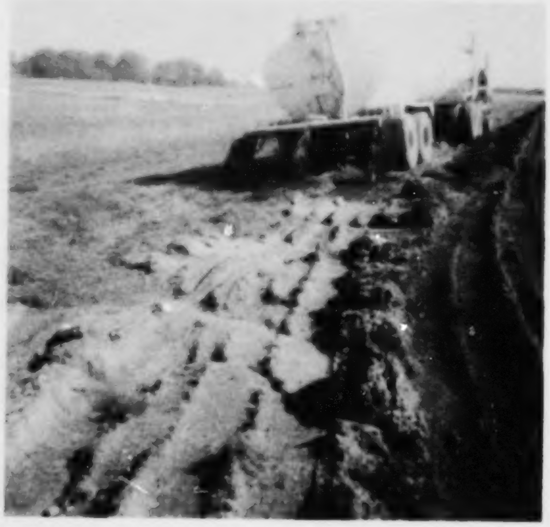


Figure 26. Tank truck applying sludge at Rhode Island site.

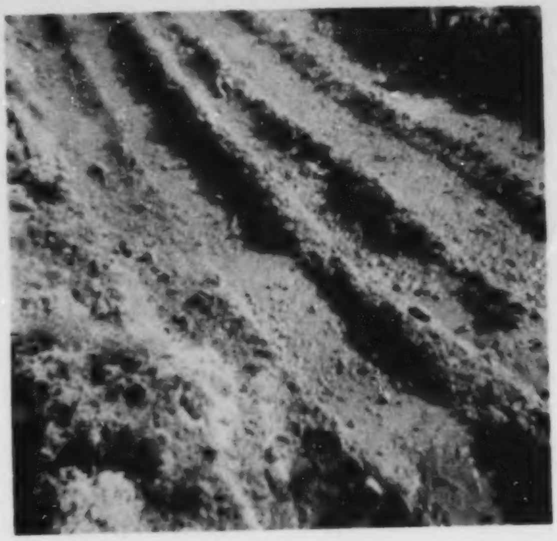


Figure 27. Treated soil about 2 hours after sludge application.

Figure 28. Rhode Island control field.

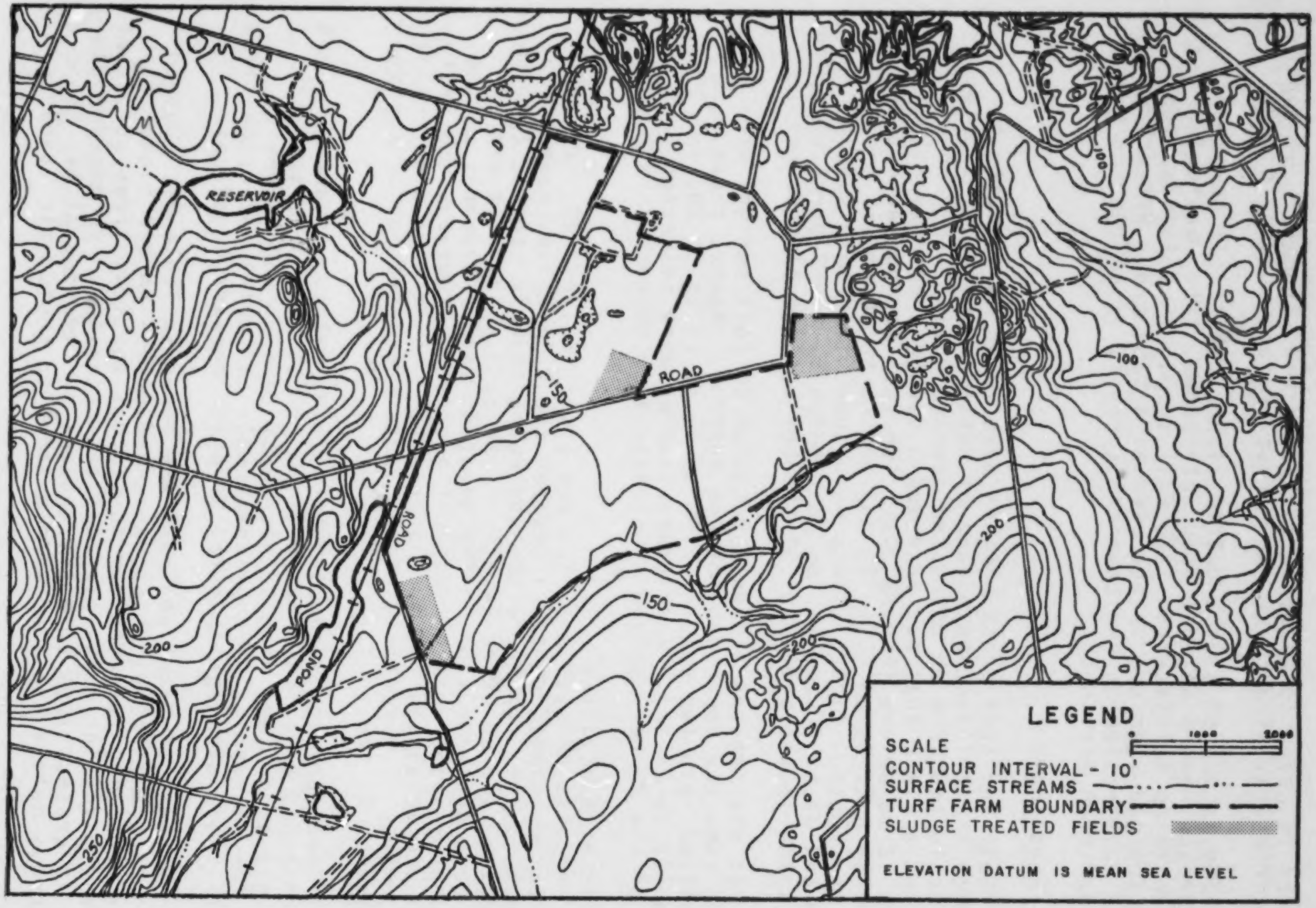

RESERVOIR
ROAD
ROAD
POND
100
150
150
200
200
200
250
LEGEND
SCALE
0
1000
2000
CONTOUR INTERVAL - 10'
SURFACE STREAMS
TURF FARM BOUNDARY
SLUDGE TREATED FIELDS
ELEVATION DATUM IS MEAN SEA LEVEL

Figure 29. Rhode Island case study site: 1976 sludge treated fields.

appeared to have increased turf quality and strength. No apparent detrimental effects on turf grass production were observed.

The impact of sludge cultivation at this site on ground and surface waters has not been determined. The monitoring program to be initiated in 1978 will supply this information. Since the sod produced is not used as a food crop, effects of sludge cultivation on the chemical composition of the sod have also not been examined.

Field Sampling

Soil and turf grass samples were taken at the site to evaluate the buildup and uptake of waste components. Samples were collected from an untreated (control) field (Figure 28) and from a field that had received a sludge application approximately 12 mo before (Figure 30). Ten soil borings were taken at depths of 0 to 30 cm (0 to 12 in) and 30 to 60 cm (12 to 24 in) from the control field. These were composited into single 0 to 30 cm and 30 to 60 cm samples for analysis. Turf grass clippings were taken in the proximity of the borings and also composited.

In the treated fields a total of 30 soil borings were made at the same two depths as for the control. Again, these were composited into two samples of 0 to 30 cm (0 to 12 in) and 30 to 60 cm (12 to 24 in). Turf grass samples were collected near each of the 30 borings and composited into three separate samples.

Results of Analysis--

Results of soil analyses are given in Table 23. Waste application significantly increased the 0.1N HCl-extractable orthophosphate, copper, zinc, and water-soluble sodium, calcium, magnesium, and chloride levels in the soil. The high orthophosphate concentration in the treated soil is probably due to phosphorus added to the detergent products. However, the orthophosphate levels in the two depths from the control plot are also high, which is indicative of the large concentration of native phosphorus in the soil.

There are indications that sodium, calcium, magnesium, and chloride had moved to a depth of 60 cm (24 in). The soil is strongly acidic and highly leached of calcium and magnesium. From the standpoint of nutrient supply and metal retention, liming the soil with agricultural dolomite appears necessary.

Results of plant analyses are given in Table 24. Concentrations of nitrogen, phosphorus, and potassium are higher than those generally reported for most grass species, irrespective of waste application. The nitrogen concentrations are exceedingly high in grasses from both the control and treated plots. None of the heavy metals analyzed were present in phytotoxic levels.

Figure 30. Rhode Island sludge treated field.

Figure 31. Rhode Island sludge storage lagoon.

TABLE 23. ANALYSES OF SOILS FROM THE CONTROL AND SLUDGE TREATED PLOTS - RHODE ISLAND SITE

Parameter	Control soil depth (cm)		Treated soil depth (cm)	
	0-30	30-60	0-30	30-60
pH	5.40	5.35	5.60	5.25
Total N, %	0.172	0.041	0.168	0.042
EC, mmhos/cm	0.22	0.32	0.75	0.70
	0.1N HCl-extractable, µg/g			
Ortho-P	92.5	46.2	250	98.7
SO_4	19	50	23	90
Fe	53.4	26.5	62.7	44.5
Mn	6.7	4.1	6.4	5.2
Cu	8.20	1.08	27.73	3.25
Ni	2.17	1.33	0.33	2.17
Pb	2.00	0.83	2.17	0.50
Cr	0.70	0.75	0.25	0.75
Cd	0.05	0.03	0.01	0.03
Zn	13.86	8.36	36.59	8.40
	Water-soluble, µg/ml			
B	0.20	0.20	0.20	0.20
Na	2.8	4.9	18	17
Ca	24	31	75	70
K	3.2	12	3.9	5.5
Mg	11.0	9.8	42.4	32.8
Cl	21	27	49	46

TABLE 24. CHEMICAL ANALYSES OF GRASSES FROM THE CONTROL AND TREATED PLOTS - RHODE ISLAND SITE

		Treated			
Element	Control	1	2	3	Average
	%				
Total N	3.83	4.51	4.10	4.50	4.37
P	0.34	0.34	0.41	0.34	0.36
K	2.19	1.88	2.69	2.28	2.28
Na	0.019	0.011	0.021	0.016	0.016
Ca	0.34	0.39	0.36	0.38	0.38
Mg	0.17	0.17	0.18	0.18	0.18
S	0.28	0.37	0.34	0.35	0.35
	μg/g				
Fe	150	158	150	192	167
Mn	93.3	47.7	45.3	53.7	48.9
Cu	12.27	12.50	16.41	14.06	14.31
Ni	12.50	5.63	13.13	14.37	11.04
Pb	4.58	4.58	6.25	3.96	4.93
Cr	9.40	5.90	5.60	11.20	7.57
Cd	0.10	0.07	0.19	0.15	0.14
Zn	44.5	43.8	63.8	52.0	53.2

Overall observations suggest that land cultivation of wastes at this site had not resulted in a significant buildup of nutrients (except for phosphorus) and heavy metals in the surface soil. Also, elemental composition of grasses was not affected by the waste treatment.

Waste Storage

No sludge storage facilities are provided at this site. The only sludge storage available is provided by the 1,900-m^3 (0.5 x 10^6-gal) sludge lagoon at the wastewater treatment plant (Figure 31). This lagoon normally provides between one and two weeks storage for sludge prior to land cultivation or landfill disposal. The estimated construction cost of the sludge holding lagoon was $200,000 (cost assigned to the operation of the treatment plant and not to sludge disposal). It is also estimated that sludge handling and maintenance costs associated with sludge disposal for the sludge lagoon and sludge pumps total approximately $4,000 per year.

Equipment Summary

The contractor hauling the sludge from the wastewater treatment plant to the land cultivation site utilizes 19-m^3 (5,000-gal) and 23-m^3 (6,000-gal) tank trucks. A portable pump, furnished by the contractor, is used to pump the sludge from the storage lagoon into the trucks.

Cultivation is accomplished with conventional tractor and plow equipment furnished and operated by the turf farm. Since plowing is a necessary part of site preparation prior to seeding a new turf crop, equipment and operating costs associated with plowing are not considered a sludge disposal-related expense by the owners.

Personnel

Personnel required to haul and spread the sludge are furnished by the hauling contractor. Personnel responsible for cultivation of the sludge-treated fields are furnished by the turf farm. One member of the treatment plant staff devotes approximately 14 hours per week to sludge disposal-related handling.

Economics

There are no capital costs associated with the current land cultivation practice at this site. Sludge storage capacity is provided by a primary and secondary sludge lagoon that is an integral part of the treatment system and not associated with the sludge disposal method utilized. No additional pumping or storage capacity was required since pumping capacity is provided by contract hauler and since the existing sludge lagoon provides adequate storage capacity.

A 19-m^3 (5,000-gal) or 23-m^3 (6,000-gal) tank truck is used to haul and spread the sludge. All capital and operation and maintenance costs associated with these trucks are absorbed by the contract hauler and reflected in the hauling rate of $0.004 per l ($0.015 per gal) in 1977 and $0.007 per l ($0.025 per gal) in 1978.

One plant employee is involved with sludge handling activities an average of 14 hours per week. In addition, a treatment plant employee spends approximately three hours per week conducting sludge analyses related to land cultivation. Labor (including fringe benefits) costs the plant $6,630 per year for all sludge disposal. Table 25 provides a cost breakdown for land cultivating sludge. For comparison purposes, the cost of landfill disposal of the sludge from this plant is also provided.

Planned Final Use of Site

This site is currently used for the production of turf, and plans are to continue this practice.

Public Response

Employees of the local newspaper, turf farm, and chemical company were questioned to determine public response to the land cultivation disposal technique at this site. Representatives of both the chemical company and the local newspaper indicated substantial public opposition had existed to some of the landfills that had been used for sludge disposal. No opposition to the present landfill or land cultivation site for sludge disposal was reported. Similarly, the turf farm representative indicated they had not had any complaints from the neighbors concerning the land cultivation activities.

Special Problems

The most significant problem presently encountered at this site is the difficulty in coordinating sludge hauling schedules to comply with turf planting schedules and appropriate weather conditions. Use of over-the-road tank trucks to spread the sludge makes disposal by land cultivation highly weather-dependent. Since the sludge is only applied to bare fields after sod has been harvested and before grass seed is planted, timing of sludge disposal and turf farming practices must be closely coordinated.

SOUTHERN INDIANA

Summary

During the summer of 1976, Company X in Indiana began land cultivating sludge from its wastewater treatment plant on a 20-ha (50-ac) field owned by a local farmer. This field was later returned to agricultural use. In April 1977, land cultivation moved to a 20-ha (50-ac) plot of a 60-ha (150-ac) field, east of the previous field. The primary goal of activities at these two fields, which constitute one land cultivation site, is the disposal of sludge. Resulting soil conditioning is a secondary benefit. Sludge applied is low in nutrients; therefore, fertilization may be required when the land is returned to agricultural use. The sludge, however, is strongly alkaline, reducing soil acidity.

TABLE 25. RHODE ISLAND SITE SLUDGE DISPOSAL COST ANALYSIS FOR CALENDAR 1976

Cost elements	Disposal method Land cultivation	 Landfill
Annual Capital Cost		
Vehicle depreciation	---	---
Stationary equipment depreciation	---	---
Building depreciation	---	---
Total annual capital cost	- 0 -	- 0 -
Annual Operating Cost		
Labor (including fringe benefits)	$ 6,630	$ 5,967
Maintenance	400	3,600
Transportation charges	13,500	112,275
Disposal charges	0	134,730
Utilities and other	0	0
Total annual operating cost	$ 20,530	$ 256,572
Total annual capital cost	- 0 -	- 0 -
Total annual cost	$ 20,530	$ 256,572
Total Sludge Hauled		
(Metric tons on a dry weight basis)*	246	2,453
Cost Per Metric Ton	$ 83	$ 105

*The sludge weighs 8.36 lb/gal at 7.2% solids.

The sludge results from the addition of lime/ferrous chloride/polymer to a primary treatment system, with waste-activated sludge subsequently mixed in. The sludge is pumped from a storage lagoon at the plant into tank trucks, then transported to the field and discharged into a railroad tank car that serves as the on-site storage facility. A tractor-drawn tank wagon is used to apply the sludge, injecting it about 40 cm (16 in) beneath the surface. Approximately 5,700 m^3 (1.5 MG) of sludge has been cultivated through the end of July 1977, with an equal quantity remaining to be cultivated in the late summer and fall of 1977.

To date, the program has been generally successful, although some odors have been detected, leading to a few complaints from nearby residents. During 1976 the odors were eliminated by initiating a program of periodic disking. Odors in 1977 were caused by anaerobic conditions developing in the sludge storage lagoons, resulting in a foul smelling sludge applied to the site. This condition was coincident with a failure of the sludge injection equipment and the application of excessive sludge on the soil surface. A large quantity of lime was added to the lagoons, and odors were essentially eliminated.

History of Land Cultivation

Land disposal of sludge was initiated by Company X in May 1976, with the leasing of 20 ha (50 ac) of farmland and the hauling of the first loads of sludge. The land was leased at an approximate rate of $444/ha/yr ($180/ac) or about $9,000 for the year. During this initial year of operation, the sludge was pumped from storage lagoons into tank trucks and hauled 27 km (17 mi) to the leased field. Each tank truck was equipped with a special rear-mounted spray plate, which spread the sludge in a 3- to 4-m (10- to 14-ft) wide pattern as the truck traversed the field. At the request of the state regulatory agency, the field was disked 2 to 4 wk after application to mix the sludge into the soil, primarily to minimize the possibility of runoff in the event of heavy rain. Approximately 6,400 m^3 (1.7 MG) of sludge was cultivated in this manner in 1976.

Prior to land cultivation, Company X experimented with several methods of disposing of its wastewater treatment plant sludge, with unsatisfactory results. Initially, the company ran a pilot cultivation program on a field behind the local landfill. However, the 4.9-ha (12-ac) field was not large enough to handle the volume. As a result, about 10 cm (4 in) of sludge were accumulated on the surface. A major rainstorm caused runoff to a nearby creek, and the program was stopped by the Indiana Water Pollution Control Board.

As a second disposal attempt, the sludge was mixed with residential refuse in the landfill. However, operating procedures required by the state regulatory agency limited the disposal of sludge to 28 m^3 (7,400 gal) per day, which was not sufficient to dispose of the generated sludge. As a last resort, in early 1976, the sludge was hauled 47 km (60 mi) to a private industrial waste recovery/disposal site. A total of 5,100 m^3 (1.35 MG) of sludge was disposed, but the cost of \$160,000, or \$31.3/m^3 (12¢/gal), prohibited long-term use of this site.

Company X has also tested approximately six to eight methods of mechanical sludge dewatering with generally discouraging results.

Site Description

This site is located near an interstate highway in southern Indiana, 29 km (18 mi) north of the Ohio River. Figure 32 locates the 20-ha (50-ac) field used for sludge cultivation in 1976 and the 20-ha (50-ac) plot used for the initial sludge applications in 1977. (The latter plot is part of a 60-ha, or 150-ac farm, all of which is available for land cultivation.) Both the 1976 and 1977 plots of land are owned by the same farmer.

Land Area and Topography--

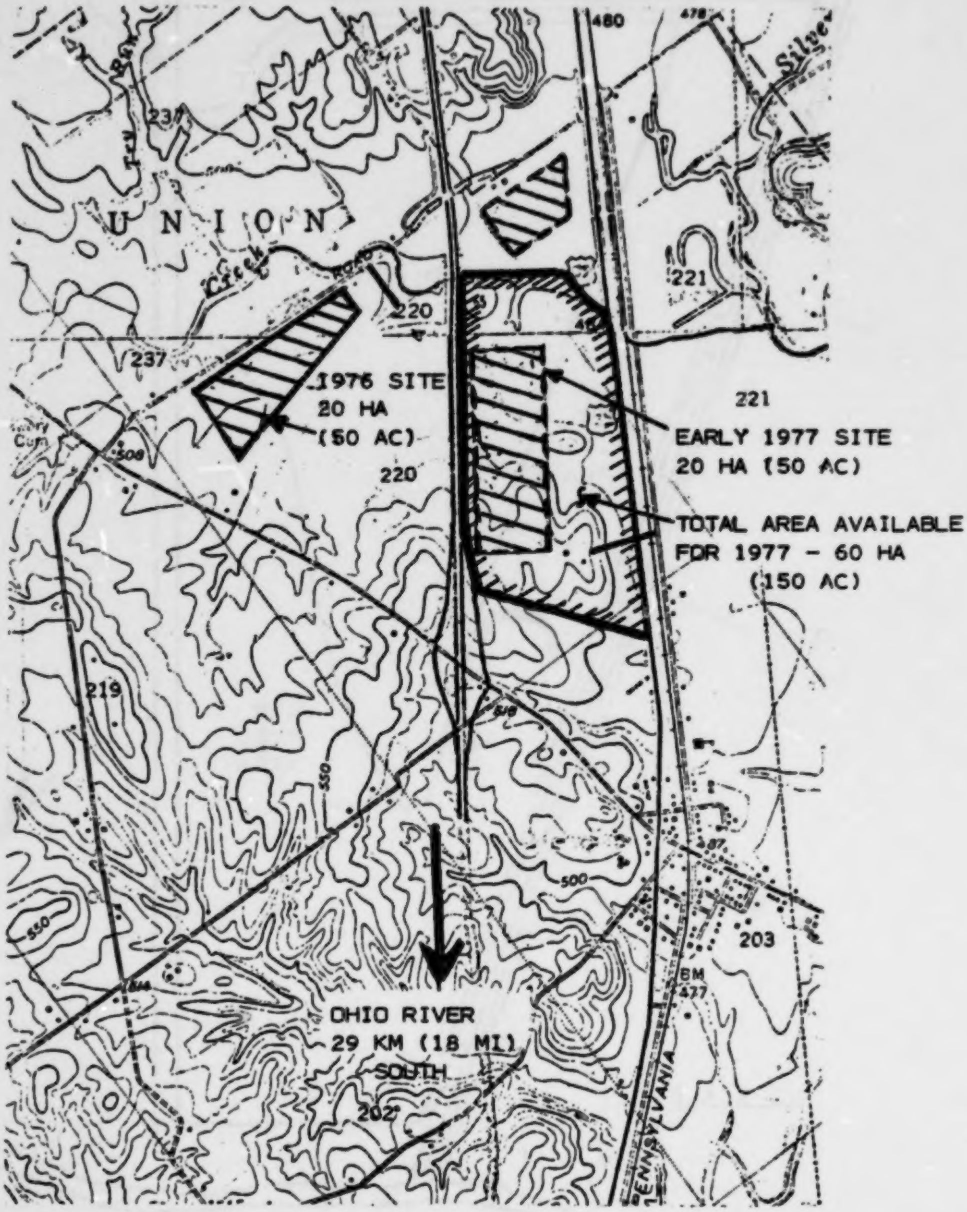
Figure 33 shows the layout of the field used in 1976, with significant features located. The field, which is highest at the west end, slopes to the northeast and southeast. There is approximately a 6-m (20-ft) drop in elevation from the high to the low areas of this field, with the lowest area along the drainage ditch.

Figure 32 shows the field used for land cultivation in 1977. This parcel slopes from the high ground at the south toward low ground at the northeast. In general, the entire area is rolling, with moderately gentle slopes and some level ground to the north.

Surface Drainage Patterns, Surface Water, and Groundwater--

The 20-ha (50-ac) field used for land cultivation in 1976 drains toward the southeast into the drainage ditch shown in Figure 33. This ditch flows northeast into a creek. The entire 60-ha (150-ac) field available for 1977 activities drains to the north, with the surface flow also entering the creek. As shown in Figure 32 this creek enters a second creek a short distance east of the site. This second creek flows south, ultimately entering the Ohio River to the south.

Only one well is located near the site. This well is about 0.4 km (0.25 mi) uphill from the field where wastes were cultivated in 1976, and is used as a potable water supply by one farmer.



UNION
Creek
220
237
1976 SITE
20 HA
(50 AC)
220
480
221
221
EARLY 1977 SITE
20 HA (50 AC)
TOTAL AREA AVAILABLE
FOR 1977 - 60 HA
(150 AC)
219
550
500
203
BM 477
OHIO RIVER
29 KM (18 MI)
SOUTH
202
PENNSYLVANIA

Figure 32. Southern Indiana site location.

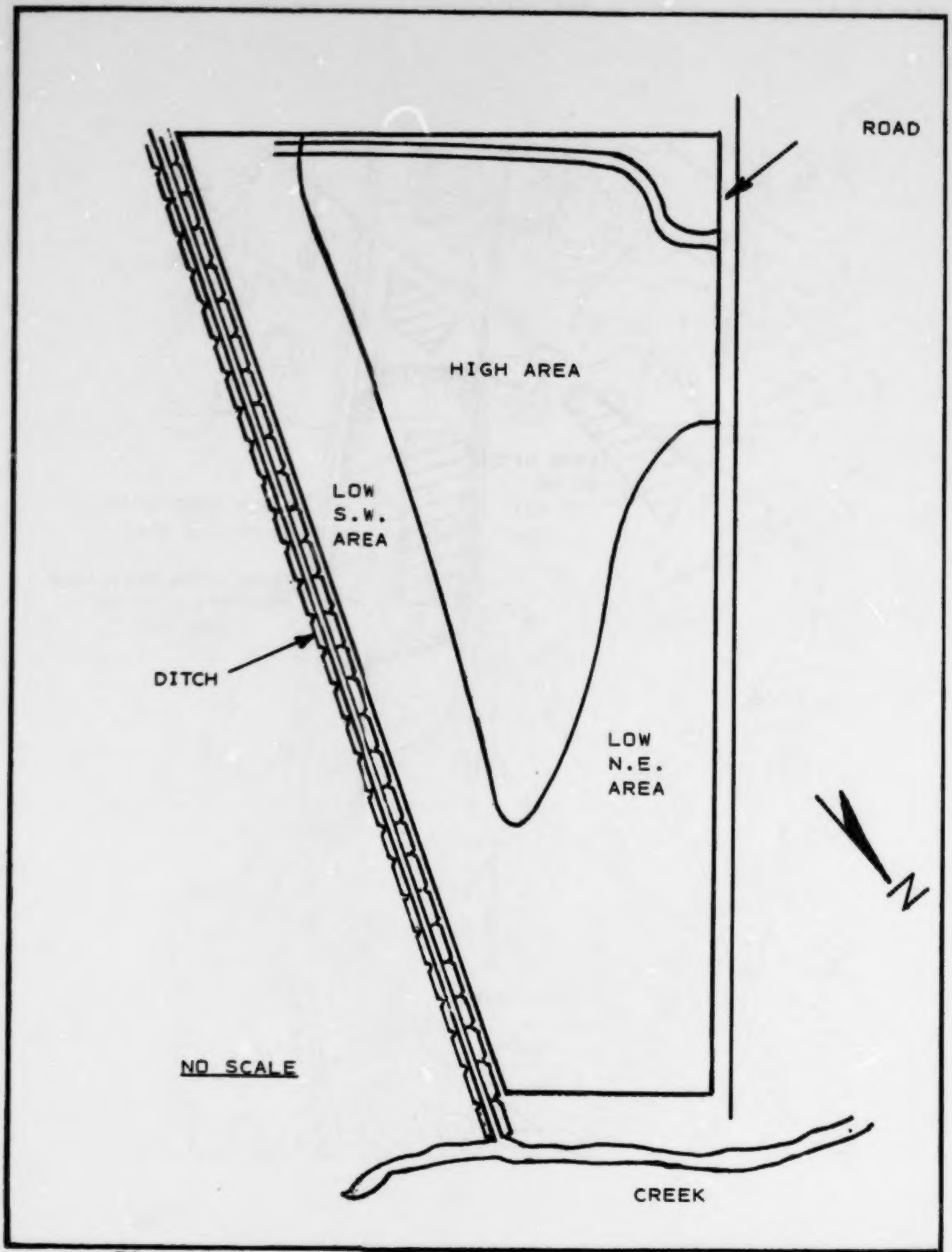

ROAD
HIGH AREA
LOW
S.W.
AREA
DITCH
LOW
N.E.
AREA
N
NO SCALE
CREEK

Figure 33 . Map of 1976 sludge disposal field.

Vegetation and Soil--

The western field, which was used for waste cultivation in 1976, was returned to agricultural use by the land owner in 1977. Winter wheat was planted in the eastern end, and corn was planted in the remainder of the field. This area was visited in late July 1977, after the wheat was harvested. At that time the corn was approximately 2 m (7 ft) tall, very green, and appeared to be as good, or better, than corn growing in surrounding fields that received no waste.

Use of the large, eastern field for land cultivation of waste sludge during 1977 precludes production of any crops. The northern, low end of the area was, at one time, in timber. Most of this land has been cleared, with several large piles of cut brush and trees scattered about. This northern section has received no sludge but may be used for land cultivation of waste later in 1977. At present the entire 60-ha (150-ac) field is covered with weeds and some grasses. A small herd of cattle was grazing the land, including the area that received waste application in the spring and early summer of 1977.

Figure 34 is a photograph of the southern, treated section of the field. The photograph, which looks west, shows weeds and brush growing on the field. The area in the foreground was most recently injected with sludge, thus the bare soil. Use of subsurface injection to apply sludge disturbs only a portion of the vegetation, as witnessed by the scattered weeds found in the otherwise bare soil areas. This is indicated in Figure 35, which is a close-up of a recently treated area.

The soil in the 1976 land cultivation area is predominantly Bartle silt loam. It is a deep, nearly level, somewhat poorly drained soil that has a slowly permeable fragipan. The surface layer (0 to 28 cm, or 0 to 11 in) is brown and neutral (due to liming); the subsurface layer (28 to 36 cm, or 11 to 14 in) is light gray and slightly acid. The subsoil is about 135 cm (53 in) thick and strongly acid.

The soils in the 1977 land cultivation field are composed of Clermont silt loam, Bartle silt loam, Jennings silt loam, and others. The Clermont soil is also poorly drained and strongly acid throughout the solum (183 cm, or 72 in thick). Jennings silt loam is deep, well-drained soil that occupies narrow ridges and short breaks between nearly level ridges and sloping hillsides.

In general, these soils are strongly acid, and low in organic matter content and natural fertility. Lower horizons are poorly drained and strongly to extremely acid, with the presence of a fragipan.

Since the waste is strongly alkaline (pH 12.4), the farm owner is willing to allow land cultivation to replace at least

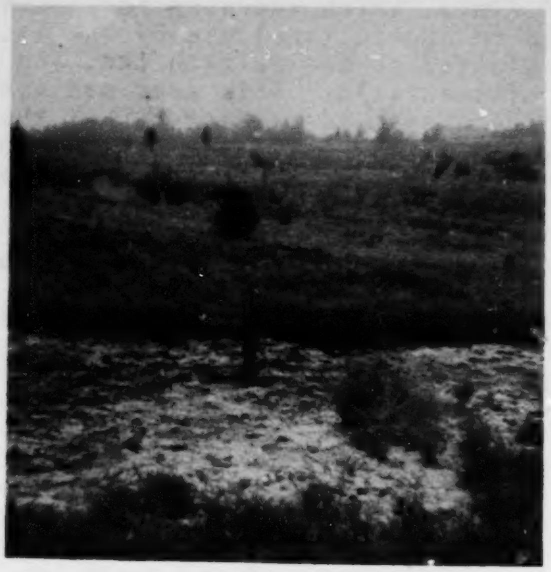


Figure 34. Area of 1977 land cultivation activities - Indiana site.

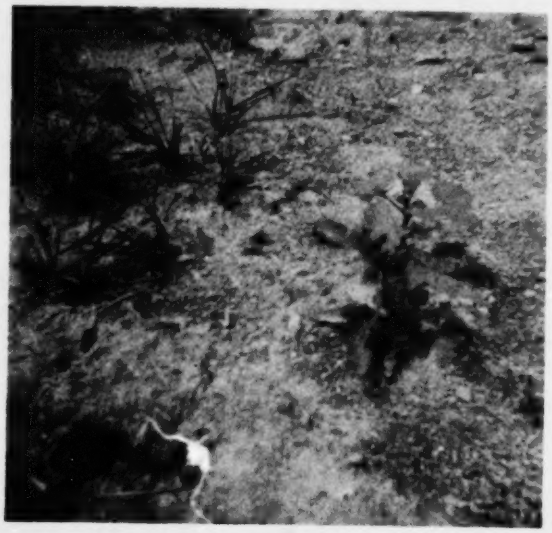


Figure 35. Vegetation on recently cultivated plot - Indiana site.

a portion of the lime normally required to maintain a proper pH. In addition, the sludge will improve soil tilth and overall physical properties of the soil.

Climate--

Area climate, as summarized in Table 26, is typical of the Ohio River Valley, characterized by warm summers with daytime temperatures of 24 to 32°C (75 to 90°F), and relatively mild winters. Daytime temperatures in the winter normally range from 2 to 10°C (35 to 50°F). January is the coldest month, and July the hottest. Annual precipitation averages 104 cm (41 in) and is relatively evenly distributed throughout the year. The climate has a significant effect on the land cultivation operations, as occasional heavy rains make the field impassible, especially in the low areas. Periods of prolonged freezing temperatures also cause cessation of cultivation activities.

Site Preparation

Preparation efforts at this site were minimal. Some work was done to upgrade and maintain the gravel access road. This road enters the 60-ha (150-ac) farm on the east side from a U.S. highway. A widened area at the end of the road has been developed, allowing trucks to turn around and also providing for open storage of equipment.

The only other preparation was the installation of an old railroad tank car. This is used for sludge storage and loading of the tank wagon employed for sludge cultivation. The tank car has been installed at the top of a low, steep bluff.

Related Studies

Company X has retained an engineering consulting firm to conduct studies at the site. Samples of soils, vegetation, and creek water were obtained from the site in May 1976, before land cultivation activities were initiated. Analysis of these samples established baseline conditions. The western field was again sampled in December 1976, after land cultivation operations on that plot were completed. Plans are to again sample the site in the fall of 1977.

Results of the sampling and analysis program are considered to be confidential and could not be released.

State and Local Regulations

This site is operated with authorization of the Division of Sanitary Engineering, Indiana State Board of Health. Table 27 summarizes conditions that were imposed by the state for site operations. These conditions (presented in two letters, dated February 26 and May 18, 1976) covered operations conducted in 1976.

TABLE 26 SUMMARY OF CLIMATOLOGICAL DATA: LOUISVILLE, KENTUCKY

Month	Precipitation	Temperature		Winds	
	Normal	Maximum	Minimum	Mean hourly speed	Prevailing direction
January	10.4 cm (4.1 in)	6°C (44°F)	-3°C (26°F)	15.9 kmph (9.9 mph)	S
February	7.6 (3.0)	8 (46)	-2 (28)	16.6 (10.3)	NE
March	11.9 (4.7)	13 (56)	2 (35)	17.4 (10.8)	NW
April	10.2 (4.0)	19 (67)	7 (45)	16.2 (10.1)	SW
May	10.0 (3.9)	25 (77)	12 (54)	13.7 (8.5)	SE
June	10.3 (4.1)	30 (85)	17 (63)	12.4 (7.7)	S
July	7.8 (3.1)	32 (89)	19 (67)	11.3 (7.0)	S
August	7.8 (3.1)	31 (88)	18 (65)	10.6 (6.6)	N
September	6.9 (2.7)	28 (82)	15 (58)	11.4 (7.1)	SE
October	6.2 (2.4)	21 (70)	8 (47)	12.6 (7.8)	SE
November	7.9 (3.1)	13 (55)	2 (36)	15.1 (9.4)	S
December	8.4 (3.3)	8 (46)	-2 (28)	14.5 (9.0)	S
Year	105.3 (41.5)	20 (67)	8 (46)	14.0 (8.7)	S

TABLE 27. CONDITIONS IMPOSED BY STATE REGULATORY AGENCY FOR INDIANA SITE OPERATION APPROVAL

Conditions Imposed February 26, 1976

1. No more than one sludge application on any portion of the site
2. No disposal operations allowed closer than 600 ft from the interstate highway
3. Sludge application must always be done by use of a spreader
4. No sludge accumulation at any point to be at a depth greater than 0.5 in
5. State agency must be notified upon start-up to allow an inspection
6. Approval becomes void in site ownership changes

Conditions Imposed May 18, 1976

1. Approval granted for use of an additional 50 ac
2. Only sludge from Company X may be disposed at the site
3. County Health Department approval required prior to start-up
4. Sludge application must not occur during inclement weather
5. Application rate not to exceed 25,000 gal/ac
6. All sludge must be disked into the soil after surface application
7. Written request must be submitted for renewal of the approval for operations after November 1, 1976

At the time of this authorization, there were no state regulations, as such, dealing with land cultivation. In the spring of 1977, a Land Applications Division was formed that will be the state agency overseeing land cultivation activities. This new division had issued no regulations at the time of this report.

At the local level, the County Health Department is the responsible agency. While concerned with health effects of this land cultivation operation, the Health Department also has not issued specific regulations.

Lack of state or local regulations has resulted in changing requirements, as shown by the fact that two letters of authorization were issued. For land cultivation in 1977, the state and county determined that surface application was no longer acceptable. The requirement was then revised to stipulate subsurface injection at a depth of approximately 40 cm (16 in).

Waste Characteristics

The sludge is composed predominantly of primary solids from a clarifier that is dosed with lime, ferrous chloride, and polymer. This sludge is pumped to one of two large sludge storage ponds, along with a minor amount of waste-activated sludge from the secondary clarifier. The combined sludge, which averages 1-percent solids, then goes to the lagoons where it is dewatered. The supernatant is pumped back to the head of the treatment works, and the sludge, at about 10-percent solids, is pumped into the tank trucks and applied to the field.

Estimated sludge production is roughly 2,270 kg or 190 m^3 (5,000 lb or 50,000 gal) per day, of which about 70 to 95 percent is the primary chemical sludge and the balance is waste-activated sludge. Tables 28 and 29 summarize sludge characteristics from the south sludge storage lagoon. Note that sludge pH and concentrations of magnesium and boron are extremely high. Percent solids increase significantly toward the bottom of the lagoon (up to 20 percent at the bottom of the lagoon). Figure 36 shows the sampling locations.

Waste Storage/Transportation

The sludge from the treatment plant is stored in two 4.3-m (14-ft) deep lagoons, each with 5,700-m^3 (1.5-MG) capacity. The lagoons are clay lined to prevent leaching to the groundwater. Storage procedure calls for 9 to 10 mo of filling and dewatering in one lagoon while the other is being emptied and the sludge is land cultivated. Because there is no disposal activity during the cold winter months, there is heavy activity from late spring through fall to provide sufficient lagoon capacity for the rest of the year.

TABLE 28. CHEMICAL CHARACTERISTICS OF SOUTH LAGOON SLUDGE FROM INDIANA SITE*

Parameter	Average	Range
pH	12.41	12.1 - 12.5
EC, mmhos/cm	7.62	1.39 - 14.9
Solids, %	11.51	9.3 - 15.9
TS, mg/l x 10,000	10.97	9.03 - 15.4
TVS, mg/l x 10,000	4.11	3.42 - 5.26
Alkalinity, mg/l as $CaCO_3$ x 10,000	11.36	7.26 - 22.0
Chlorides, mg/l	56.78	19.7 - 122.5
Total P, %†	0.226	0.11 - 0.35
Total Kjeldahl nitrogen, %	0.034	0.012 - 0.045

*Analysis of three lagoon samples.
†Dry weight basis.

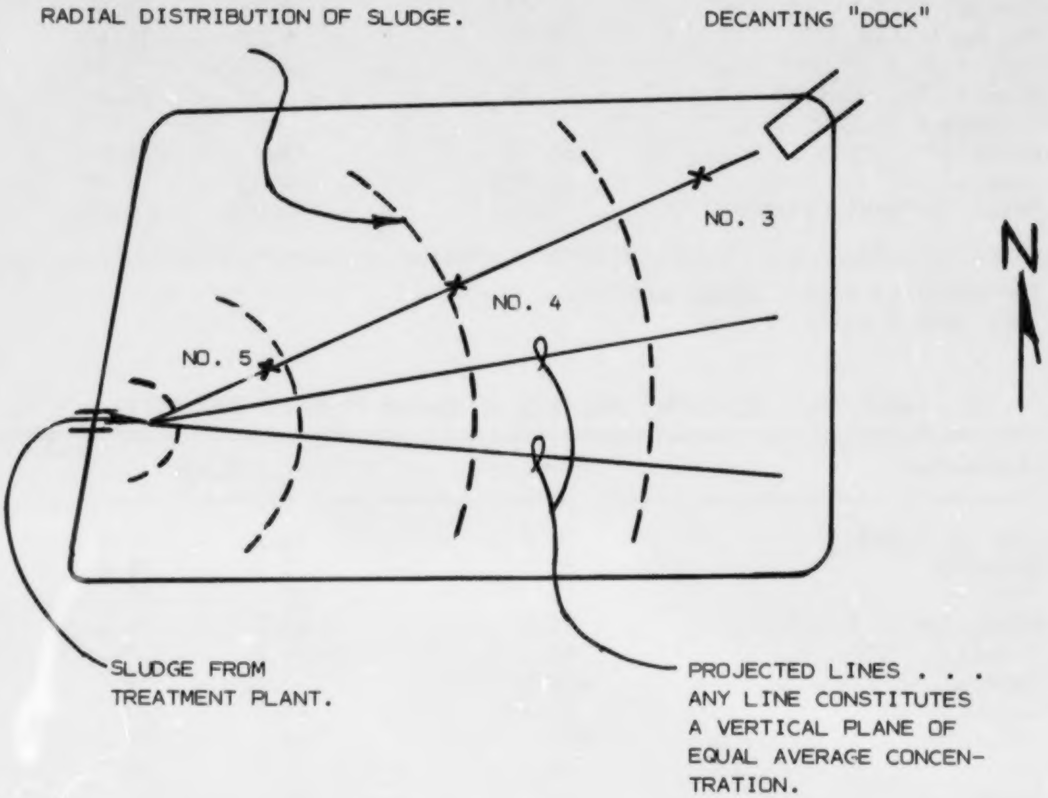
TABLE 29. ELEMENTAL ANALYSIS OF SLUDGE FROM INDIANA SITE*

Parameter	Average	Range
Iron (x 1,000)	39.1	18.8 - 77.1
Chromium	30.3	23.8 - 58.6
Zinc	163	122 - 322
Magnesium (x 1,000)	34.5	22.7 - 79.3
Nickel	65.1	51.8 - 154
Cadmium	5.62	3.45 - 19.4
Copper	62.3	44.6 - 120
Potassium	658	354 -1,950
Lead	64.3	50.4 - 138
Boron	492	328 -1,030

*Analysis of three lagoon samples. Concentration in µg/g dry weight.

The south sludge lagoon (Figure 37) was emptied first in 1977. Sludge in the north lagoon (Figure 38) will be cultivated later in the year. This lagoon was full when visited, with the south lagoon receiving newly generated sludge. A dry crust of sludge, about 5 cm (2 in) thick, is found on the surface. Below the crust, the sludge is much thinner, at less than 10-percent solids.

The waste is trucked by a private hauler 27 km (17 mi) to the field in three trucks of 6-, 15-, and 21-m^3 (1,600-, 4,000-,


RADIAL DISTRIBUTION OF SLUDGE.
DECANTING "DOCK"
NO. 3
NO. 4
NO. 5
N
SLUDGE FROM TREATMENT PLANT.
PROJECTED LINES . . . ANY LINE CONSTITUTES A VERTICAL PLANE OF EQUAL AVERAGE CONCENTRATION.

NOTE: SAMPLES NO. 3, NO. 4, AND NO.5 DENOTE THE APPROXIMATE LOCATION OF WEEKLY SAMPLES FROM THE SOUTH LAGOON DURING THE WEEKLY SAMPLING PERIOD.

Figure 36. Sample locations (south lagoon) - Indiana site.

Figure 37. South sludge lagoon - Indiana site.

Figure 38. North lagoon sludge - Indiana site.

and 5,500-gal) capacities. Short-term, on-site storage is provided by the railroad tank car previously discussed and shown in Figure 39. The trucks pump their sludge load into this tank car on arrival at the site, then return to the storage lagoons for more loads.

Table 30 indicates the sludge transport rates achieved during the land cultivation activities of 1976. At that time, the 21-m^3 (5,500-gal) truck was not in operation; a small, 4-m^3 (1,000-gal) truck was used. Also, the trucks were used to spread sludge on the land, thereby spending more time at the site and reducing the daily trips.

TABLE 30. 1976 SLUDGE TRANSPORTATION

Month	No. Loads	Working Days	Monthly Total	
May	22	2	108 m^3	(28,600 gal)
June	85	9	419 m^3	(110,800 gal)
July	211	23	1,073 m^3	(283,600 gal)
August	241	25	1,941 m^3	(512,800 gal)
September	121	19	1,123 m^3	(296,600 gal)
October	110	18	1,120 m^3	(296,000 gal)
November	63	11	709 m^3	(187,200 gal)
	853	107	6,493 m^3	(1,715,600 gal)

Waste Application

Subsurface injection is now used to apply sludge to the site. A 13-m^3 (3,500-gal) IME tank wagon with plows (Figure 40) injects the sludge to a depth of 40 cm (16 in). This tank wagon is pulled by a large conventional farm tractor (Figure 41).

Subsurface injection at a depth of 40 cm (16 in) presents two problems. Most significant is that anaerobic degradation of the sludge can normally be anticipated at this depth. Anaerobic degradation occurs at a much slower rate than does aerobic degradation, thereby greatly increasing the allowable time between sludge applications to avoid overloading. In addition, the decomposition products have a greater probability of creating adverse environmental impacts for anaerobic conditions than for aerobic conditions. Secondly, deep injection (at 40 cm) is physically more difficult than is shallower injection (e.g., at 20 cm). This requires that a larger tractor and/or slower speeds be used. The net effect is an increase in operating costs.

In operation, the tractor draws the tank wagon to the base of a small bluff located below the railroad tank car. Sludge is gravity fed into the tank wagon. When filled, the tank wagon proceeds to the area being land cultivated for injection. The

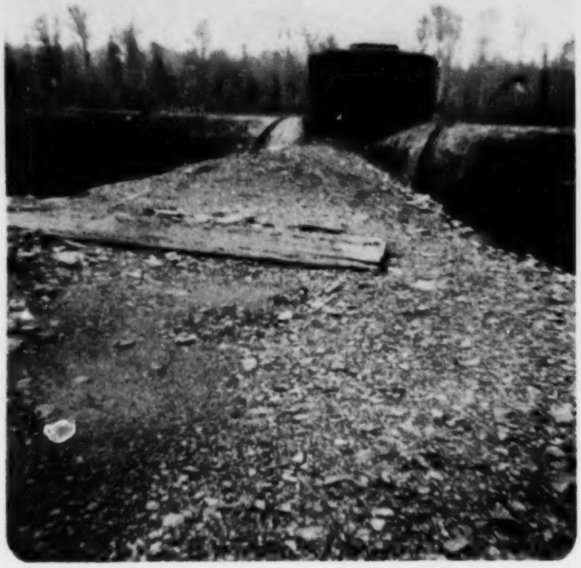


Figure 39 . Tank car for sludge storage.

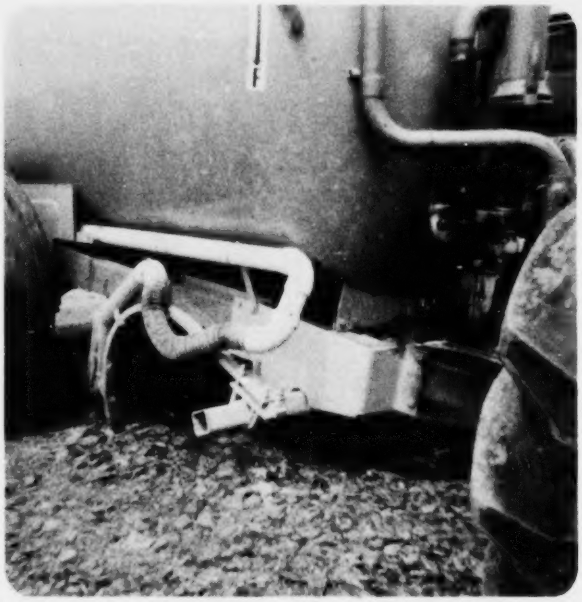


Figure 40 . Tank wagon showing plow and injector.

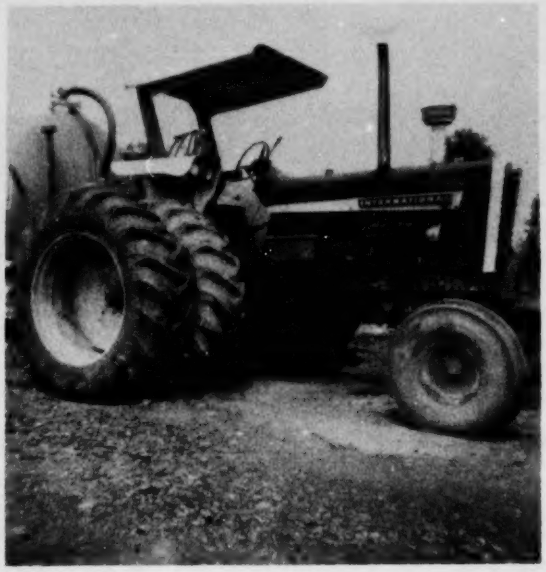


Figure 41 . Tractor used in sludge injection.

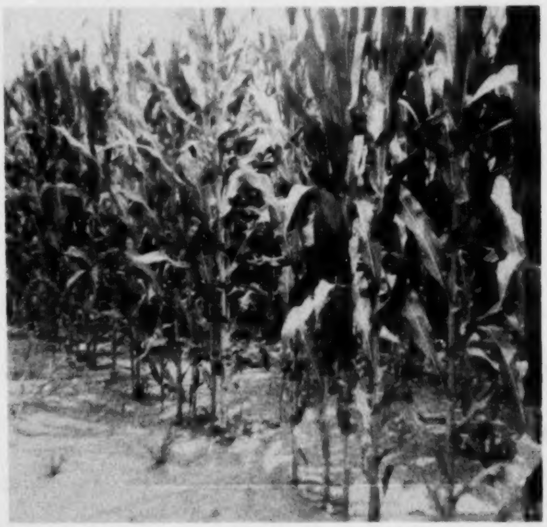


Figure 42. Corn in 1976 field - Indiana site.

State Board of Health authorized a maximum loading of 234 m^3/ha (25,000 gal/ac); however, actual loading was somewhat higher. One lagoon, of about 5,700 m^3 (1.5 MG), was cultivated on 20 ha (50 ac) for a loading of 285 m^3/ha (30,000 gal/ac). At 10-percent solids this is a loading rate of 28,000 kg/ha (25,000 lb/ac) of dry solids.

The hauler, who is also responsible for the land cultivation activities, is in full control of the sludge application rate and frequency, and works with the farm owner to determine the application area. Due to occasional muddy conditions, low lying areas are generally more lightly loaded than are high, more quickly drying, areas of the field.

The 20-ha (50-ac) field used for 1976 sludge application (Figure 42) was not land cultivated in 1977. However, the state has given approval for additional waste applications. The hauler may reuse this plot in the future, after completing injection on the current 60-ha (150-ac) field.

Environmental Factors

At the present time, the state of Indiana is in the process of developing standardized guidelines for sludge-spreading operations. The State Land Applications Division has ultimate jurisdiction over the site. Currently, the authorities in this division seem satisfied with the program, although some further interpretation of application rates and disking requirements seems necessary.

There is no continuous monitoring at the site. However, extensive sampling of soil, plants, and stream water was conducted in May 1976, before the operation began. Follow-up tests were conducted in December 1976 to determine the effects of waste application activities on these environmental components. Results of the tests, conducted by a consulting firm retained by Company X, are considered confidential. However, some information was obtained. General conclusions concerning one-time application of wastes to the western field are that soil pH, and Ca and phosphorus levels have increased, and a buildup of Na is evident. There is also an apparent increase in B and Ni levels. Borates used in some of the products produced by Company X are the probable source of B. One sludge sample, taken in the summer of 1976, showed B concentrations of up to 60 ppm. Reformulation of the products is expected to sharply reduce these concentrations, as evidenced by a June 1977 waste sample with a B concentration of 6.9 ppm. The company is at a loss to explain the Ni increase, since no nickel is used in the plant.

It is not clear how much buildup and uptake of B may have occurred in the treated field. Grass samples from a treated area showed a concentration of 22 ppm, while the same grass type in two control areas had concentrations of 4.8 ppm and 21 ppm.

Economic Summary

Company X contracts with a private hauler for all sludge hauling and spreading operations. During 1976, the hauler disposed of 6,490 m^3 (1,715,000 gal) of sludge for a fee of \$120,000 (\$18.50/m^3, or 7¢/gal). This fee included all operating and maintenance costs for the trucks, tractors, and tank wagon; the salaries and fringe benefits for the hauler and two drivers; and profit. The equivalent cost to transport all this sludge to the industrial waste recovery/disposal operation used previously would have been approximately \$240,000. For 1977 the charges have increased to \$19.75/m^3 (7.5¢/gal). This increase reflects the increasing cost of labor and fuel, and amortization of additional equipment purchased by the hauler. The income received from Company X is utilized by the hauler to pay the farmer for use of the land. For 1977 this cost is approximately \$10,000.

Additional costs borne by Company X include \$5,000 for sludge and leachability tests, about \$3,000 for each series of soil analysis, \$2,000 for lime added to the storage lagoon in the spring of 1977 (for odor control), and \$500 paid to the hauler to plow the newly cultivated areas in the spring of 1977. Other direct cost figures are not available, such as time contributed by management personnel at Company X, including the chief engineer who is responsible for the project.

Equipment Summary

Equipment owned by the hauler and used for the land cultivation operation consists of the following:

- Two farm tractors (as shown in Figure 41)
- One IME injector and tank wagon (in Figure 40) with a capacity of 13 m^3 (3,500 gal)
- One lagoon pump to agitate and pump sludge from the storage lagoons to the transport trucks
- One tank truck of 21-m^3 (5,500 gal) capacity;
- Two vacuum trucks of 6- and 15-m^3 (1,600- and 4,000-gal capacity
- One railroad tank car for on-site sludge storage and transfer to the tank wagon (Figure 39).

Planned Final Site Use

The land will continue to be used for agricultural purposes. Sludge disposal is an intermittent use of the land, creating a

1-yr idle period for the particular field undergoing sludge land cultivation. This is typified by the western field, which was used for sludge disposal in 1976 and was planted in winter wheat and corn in 1977. Figure 42 shows the corn in late July 1977, which appeared to be of excellent quality when visually compared to surrounding fields of corn.

Public Response and Problems

Initially, there was some adverse response from local residents due to odor problems and the erroneous notion that the sludge was raw sewage. By working closely with state regulatory agencies and the County Health Department, by talking to local residents to discuss the operation, and by doing everything possible to appease those concerned, company X has been able to gain acceptance for the program. Being a consumer-oriented company, it is essential to keep the program free from adverse publicity.

Odor complaints received in 1976 were resolved by instituting a program of disking shortly after sludge spreading and at 2- to 4-wk intervals thereafter. New odor complaints were lodged in the spring of 1977. Company X applied lime to the sludge storage lagoons and had the hauler plow the waste applied areas to solve the odor problems. Regulatory agencies have also requested the deep injection (40 cm) of sludge in an effort to overcome odors.

About mid-August of 1976, the sludge solids level in the lagoon rose to 15 percent, and loading of the trucks became a time-consuming problem. At this time, it was necessary to start adding water and agitating the lagoon to facilitate loading. The major lesson learned from this operation was that it is mandatory to use a combination mixing and loading device to reduce truck loading time and to get proper top to bottom mixing of the sludge in the lagoon. Suitable equipment is available in the form of a special portable version of a high-capacity, low-head, centrifugal pump. Excess water pumped to the lagoon to aid in pumping out the high solids sludge totaled approximately 1,510 m^3 (400,000 gal) and significantly increased the costs of the entire operation.

ODESSA, TEXAS

Summary

The city of Odessa, Texas, is conducting a pilot program for land cultivating shredded municipal solid wastes. This soil enrichment program is being implemented on a land cultivation site west of Odessa, and has two basic goals: to improve soil conditions and to reduce waste disposal costs.

- Improve soil conditions. Application of refuse to the land will improve soil fertility by increasing the organic matter content and water holding capacity of the soil. Thus the overgrazed land in this semi-arid region may be able to support more vigorous vegetation, increasing its grazing potential.

- Reduce waste disposal costs. Implementation of the program at this site, which is near the city's waste generation centroids, may be more economical than continuation of conventional sanitary landfilling at more remote present and future sites.

The land cultivation site is located 8 km (5 mi) west of Odessa on State Highway 302. A total of 607 ha (1,500 ac) is leased from a local rancher at a nominal rate of $1/yr. The site itself is flat, gradually sloping toward the southeast. This slope is in the direction of Monahan's Draw, which is an intermittent stream and the area's only significant drainage system. Natural vegetation consists primarily of low-growing mesquite and sparse grass. Soils in the area are sandy to loamy, allowing the infrequent precipitation to quickly evaporate.

Shredded municipal refuse is being land cultivated alone and in combination with septic waste and primary sewage sludge. About 60 percent of the ferrous metals present in the city's refuse are magnetically removed from the shredded solid waste before it is applied to the land. Land cultivation activities were initiated in the summer of 1974. Waste had been applied to a total of 41 ha (101 ac) as of late 1976. During that year only about 26 percent of the city's collected refuse was cultivated, since the program was still in an experimental stage.

Each parcel of land will receive only a single application of waste. Current application rates range from 134 to 278 t/ha (60 to 124 tons/ac). The optimum application rate has not yet been determined. For the Odessa program, the optimum application rate is defined as the minimum rate that will yield a reasonable improvement in soil characteristics as measured by increased production of vegetation. Optimum application rates and environmental effects are currently being studied.

Chemical analyses of the surface soil and two plant species - wild geranium and buckwheat - indicated that land cultivation of municipal refuse in the first year did not adversely affect the soil chemical properties or quality of vegetation at the site.

Ranch grasses sown on the enriched soil have begun to establish a reasonable cover. Results to date are encouraging and show promise of success. This has led the city to set a goal of land cultivating 75 percent of the city's refuse in 1977, ultimately increasing the goal to 90 percent.

History of Land Cultivation at Odessa

In 1969, the city of Odessa was faced with newly passed state legislation requiring the phase-out of the existing open dump disposal of solid wastes. To meet the more stringent environmental requirements, the city developed a sanitary landfill at the dump site, 6 km (4 mi) from the city center. In early 1973, it was projected that the landfill would be full by the year's end. A survey of possible replacement sites revealed that all nearby sites offered only limited capacity, while large capacity sites were located 25 km (15 mi) or more from the service area centroid. City officials determined that costs for waste transportation to the more distant sites would increase significantly if conventional sanitary landfill practices were continued. A cost analysis indicated that each 1-mi increase in haul distances would add nearly $16,000 annually to city costs.

City officials also evaluated soil conditions in the region. Cattle provide the agricultural base in the Odessa area. In the past, the land was overgrazed with much of the bare topsoil lost by wind erosion. Since the region receives little rainfall (less than 36 cm yearly average), it was difficult to reestablish vegetation to retard this erosion.

In early 1973, representatives from the University of Texas outlined the concept of a soil enrichment program to city officials. This program would involve land cultivation of the city's municipal solid waste to increase the soil's water-holding capacity and organic content to provide improved vegetative growth on the land. Since this program would also provide at least a partial alternative to the sanitary landfill, the city embarked on a pilot soil enrichment program.

In March 1973, the city entered into an agreement with the Newell Manufacturing Co. to acquire its Model 60104 solid waste shredder. In 1974, the city leased 607 ha (1,500 ac) of rangeland from a local rancher. Application of shredded solid waste on this land began in the summer of 1974. Initially, waste was applied at the rate of 90 t/ha (40 tons/ac) on 12.5 ha (31 ac) of land. Shredded waste was trucked to the site and spread by a track dozer. Soil incorporation was accomplished using a tandem disk pulled by a standard farm tractor. This arrangement worked but was slow, and the disk did not thoroughly mix wastes into the soil. Because of these disadvantages, field trials were conducted in October 1975 to evaluate alternative rototilling machines. Results of the trials led to the purchase of a Buffalo Bomag MPH-1 soil stabilizer.

Site Description

The city of Odessa is located in west Texas, about 185 km (113 mi) southwest of Lubbock, as shown in Figure 43. Approximately 607 ha (1,500 ac) of land, in two parcels, is leased for land cultivation. This land is about 8 km (5 mi) west of the city on State Highway 302 (Figure 44). The site, in addition to receiving shredded solid waste, accepts sewage sludge and septic waste to raise the carbon/nitrogen ratio and moisture content of the waste/soil mixture. Figure 45 shows the field layout where wastes are currently being applied. Refuse is being applied alone and in combination with each of the two sludges.

Topography and Vegetation--

Topography at the site and the surrounding area is a very gently undulating plain with no prominent hills or distinguishing features. This area is located in the Midland Basin at the southern end of the Texas High Plains. The land slopes gradually from the northwest to the southeast. This slope allows surface drainage toward Monahan's Draw to the southeast. Monahan's Draw is an intermittent stream, containing water only following heavy rains, and is the area's only major drainage system.

Natural vegetation at the site includes low-growing mesquite, wild geranium, broomweed, leman's love, plains bristle, cline's grass, blue grama, side oats grama, tumbleweed, wild buckwheat, and cactus. In the fall of 1976, five ranch grasses were sown on the areas that have received waste applications. Four of these grasses - plains bristle, cline's grass, blue grama, and side oats grama - occur naturally. The fifth sown grass is African blue, which is not a native species. These five grasses were sown to provide feed for grazing cattle as part of the soil enrichment/range improvement aspect of the operation. Early frosts in the winter of 1976 killed the grasses before they could become established. Plans are to reseed in the spring of 1977.

Groundwater, Soil, and Climate--

The nearest water well is located approximately 1.2 km (0.75 mi) east of the site. There are presently no monitoring wells at or near the land cultivation site. Groundwater in this area, found at a depth of about 27 m (90 ft), is of poor quality. Chloride levels are quite high (over 1,000 ppm), as are TDS (500 to 1,000 ppm) and sulfates.

The soils in the land cultivation field are moderately to well drained, calcareous rangeland with moderate permeability. The major soils are of the Ratliff series. These soils have calcareous, moderately alkaline, grayish brown loam A horizons and clay loam B horizons, with a zone of lime accumulation

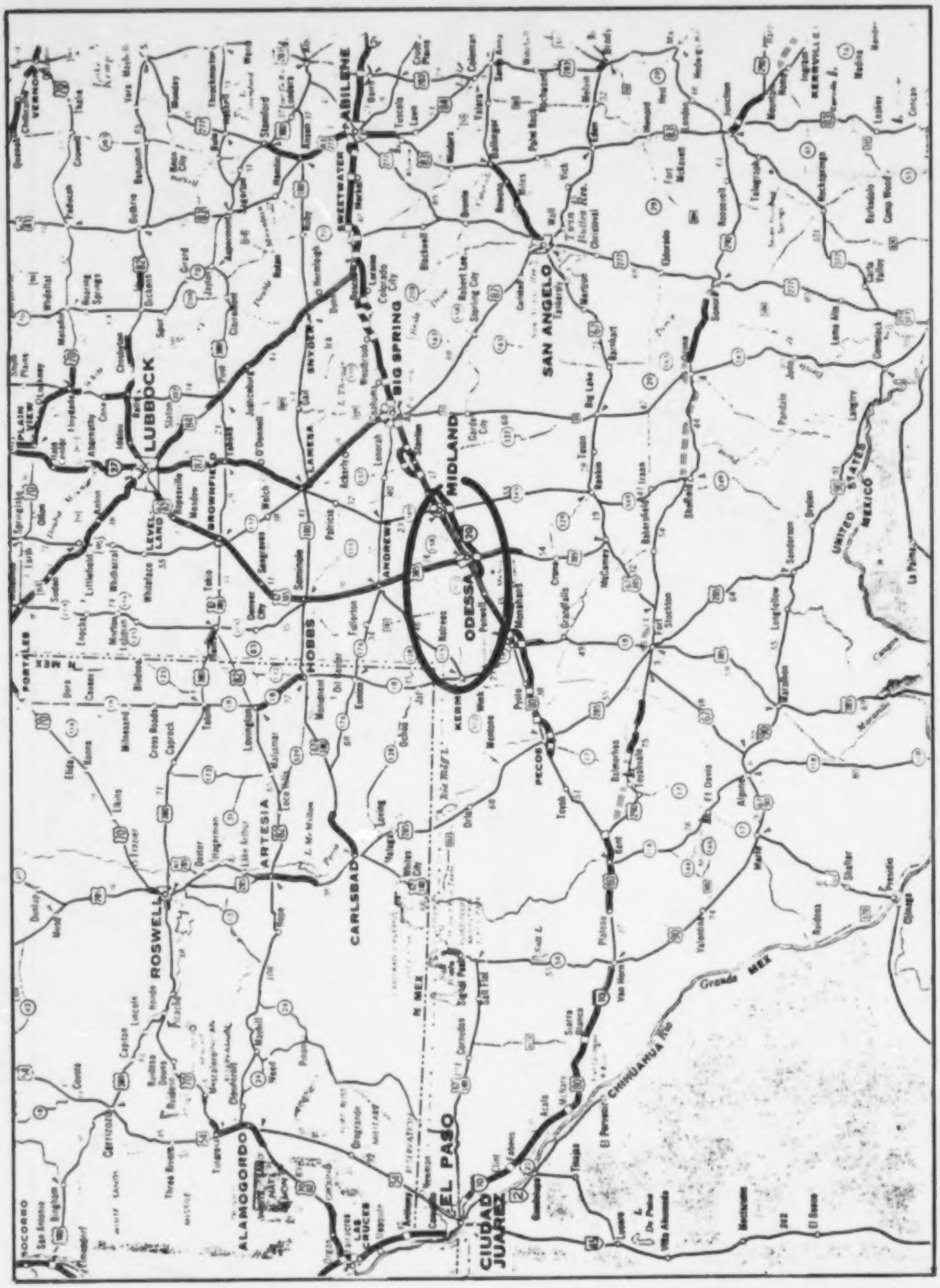

VERNON
PLAIN VIEW
LUBBOCK
LEVELLAND
BROWNFIELD
SNYDER
LAMESA
SWEETWATER
ABILENE
BIG SPRING
MIDLAND
ANDREWS
ODESSA
KERMIT
SAN ANGELO
HOBBS
PECOS
CARLSBAD
ARTESIA
ROSWELL
ALAMOGORDO
LAS CRUCES
EL PASO
CIUDAD JUAREZ
N. MEX
CHIHUAHUA
UNITED STATES
MEXICO
KERRVILLE

Figure 43. Location of Odessa, Texas.

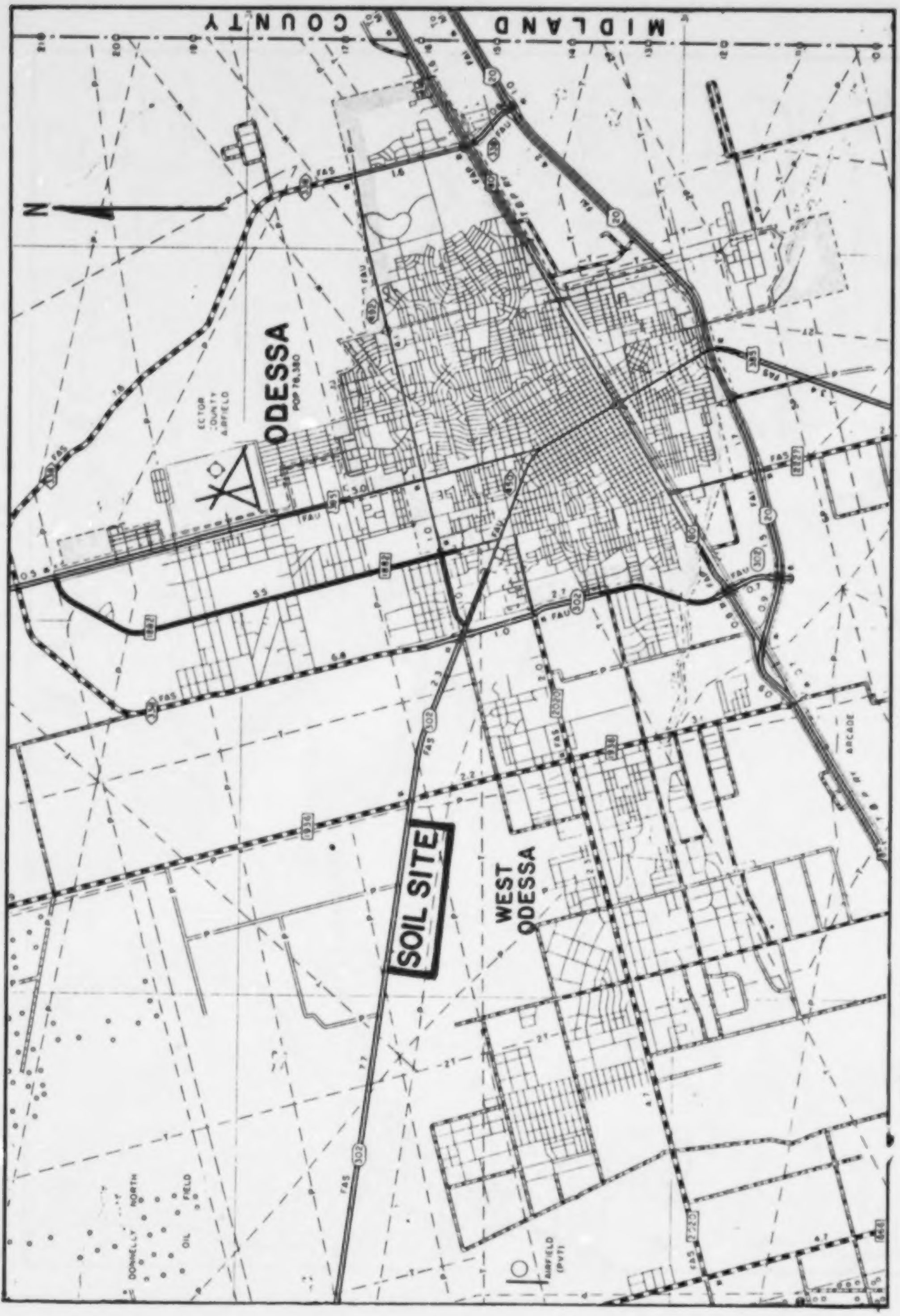

MIDLAND COUNTY
N
ODESSA
POP 78,380
ECTOR COUNTY AIRFIELD
SOIL SITE
WEST ODESSA
DONNELLY NORTH OIL FIELD
AIRFIELD (PVT)
ARCADE

Figure 44. Location of soil enrichment site, Odessa, Texas.

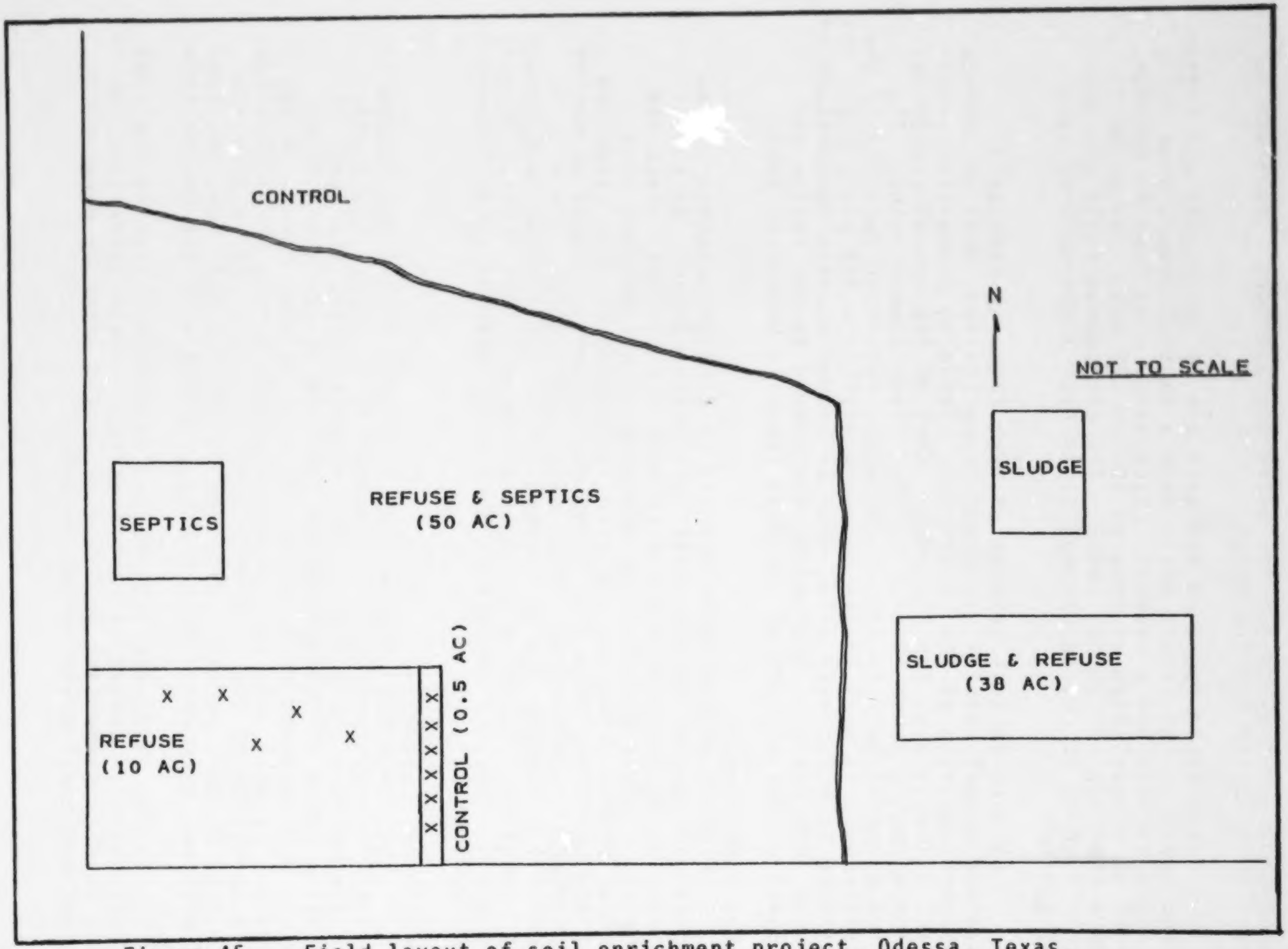

CONTROL
N
NOT TO SCALE
SLUDGE
SEPTICS
REFUSE & SEPTICS
(50 AC)
SLUDGE & REFUSE
(38 AC)
X X X X X X
CONTROL (0.5 AC)
X X X X X
REFUSE
(10 AC)

Figure 45 . Field layout of soil enrichment project, Odessa, Texas.

beginning about 64 cm (25 in) below the surface. The solum is more than 152 cm (60 in) thick.

Other soils found in the area are of the Faskin and Cottonwood series. The Faskin soils have a neutral brown, fine sandy loam A horizon and a reddish, thick sandy clay loam Bt horizon, with an accumulation of lime at 107 cm (42 in). The solum is more than 152 cm (60 in) thick. The Cottonwood soils are very thin (7.6 to 30 cm) calcareous soils over light-colored beds of gypsum.

Climate in this portion of west Texas is semi-arid. Average annual rainfall is about 36 cm (14 in), with an average evaporation rate of 183 cm (72 in). Table 31 summarizes pertinent climatic data for the area. Most of the annual precipitation normally comes in four to five heavy summer rains. The high evaporation rate and low moisture retention capacity of the soil result in very little moisture available for plant use. The climate is relatively mild, with an annual average temperature of about 18°C (64°F). High winds are common to the region and result in the erosion of the dry, sparsely vegetated soil.

Site Preparation--

Minimal efforts were devoted to site preparation. Some brush was removed before waste application began. No runoff diversion or drainage facilities were constructed, since the sparse rainfall and drainage patterns do not warrant such installations. Because the site is located on flat rangeland at some distance away from homes and highways, visual screening was deemed unnecessary. After waste application, the site is somewhat unsightly due to exposed refuse until subsequent growth of vegetation (native or seeded) provides visual cover. (Figure 46 shows the older cultivated area after partial establishment of vegetation.)

Regulatory Controls--

The Texas State Department of Health (TSDH) has responsibility for regulating waste disposal sites within the state. If any odors emanate from a land disposal site, the Texas Air Quality Board (TWQB) can become involved in its supervision. Also, any leachate from a disposal site is the concern of the board. In 1974, the city received a permit from the TSDH allowing operation of the soil enrichment program. All wastes are covered by this permit. Since odors and leachate have not been a problem, only the TSDH has been involved with the Odessa site.

In May 1976, the TWQB issued guidelines covering the land cultivation of industrial solid wastes. These guidelines, which are briefly summarized in Table 32, could later be expanded to cover municipal solid wastes as well.

TABLE 31. SUMMARY OF CLIMATOLOGICAL DATA: ODESSA, TEXAS

Month	Precipitation	Temperature		Winds	
	Normal	Maximum	Minimum	Mean Hourly Speed	Prevailing Direction
January	2.0 cm (0.8 in)	14^{o}C (57^{o}F)	-1^{o}C (31^{o}F)	15.3 Kmph (9.3 mph)	S
February	1.5 (0.6)	16 (61)	2 (35)	17.7 (11.0)	SW
March	1.0 (0.4)	21 (69)	6 (41)	19.0 (11.8)	S
April	2.0 (0.8)	26 (78)	11 (51)	19.5 (12.1)	SSE
May	5.3 (2.1)	30 (86)	16 (61)	19.1 (11.9)	SSE
June	4.1 (1.6)	34 (93)	21 (69)	18.7 (11.6)	SSE
July	4.8 (1.9)	34 (94)	22 (71)	16.1 (10.0)	SSE
August	3.8 (1.5)	34 (94)	21 (70)	15.0 (9.3)	SE
September	4.6 (1.8)	31 (88)	17 (63)	15.1 (9.4)	SSE
October	4.3 (1.7)	26 (79)	12 (53)	15.1 (9.4)	S
November	1.3 (0.5)	19 (66)	4 (39)	15.3 (9.5)	S
December	1.8 (0.7)	16 (60)	0 (32)	15.4 (9.6)	SW
Year	36.5 cm (14.4 in)	25 (77)	11 (52)	16.7 Kmph (10.4 mph)	SSE

Figure 46 . Refuse application area with partial establishment of vegetation

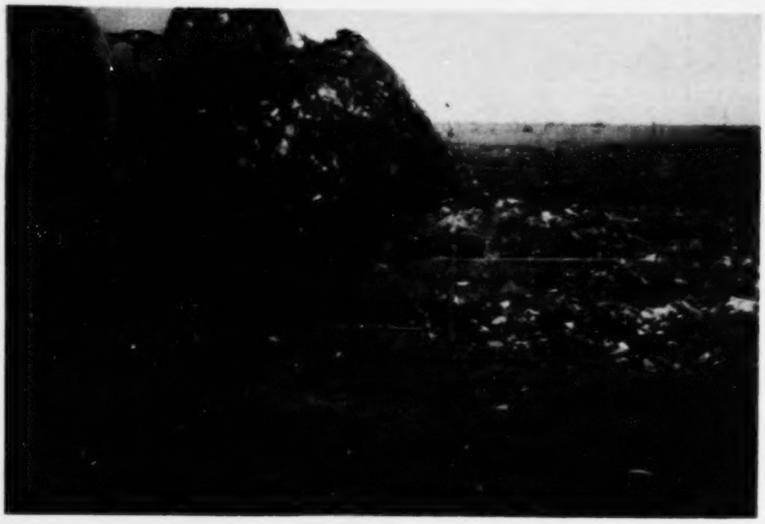


Figure 47 . Refuse application from transfer truck.

TABLE 32. TEXAS WATER QUALITY BOARD LAND CULTIVATION GUIDELINES SUMMARY

Item	Guideline (Summary Statement)
• Soils	• Should be deep, prefer high clay and organic content.
• Topography	• Prefer surface slope less than 5 percent.
• Climate	• High net evaporation, median mean temperature, moderate 24-hr, 25 yr frequency maximum rainfall.
• Surrounding Land Use	• Sparsely populated, or provide buffer and locate downwind from any nearby residence.
• Groundwater Conditions	• Avoid shallow potable groundwater. If not possible, provide vegetative cover, avoid high application rates, monitor groundwater quality.
• Application Rates	• Waste composition analysis (minimum): Cd, P, Total N, Zn, Cu, Ni, As, Ba, Mn, Cr, Cd, B, Pb, Hg, Se, Na, Mg, Ca.
	• Determine soil cation exchange capacity (CEC).
	• Total metals application over site life should be less than 50 percent of CEC of top 1 ft of site's soil.
	• If crop grown and harvested at site, total metal application in 30 yr period should be less than 5 percent of CEC.
	• Total N applied, less than 125 lb/ac/yr.
	• Annual free water applied in waste should be less than annual evaporation rate.
• Operational Restrictions	• All runoff must be contained (use dikes or collection basin).
	• Soil pH must be maintained at 6.5 or greater.
	• Mix waste into soil as soon as possible.
	• Vegetation for human or animal consumption must be analyzed for metals contained in the waste before feeding.

Waste Characteristics

Three waste types are being land cultivated at Odessa: shredded municipal solid waste, septic tank waste, and municipal sewage sludge. The city wastewater treatment plant provides only primary treatment, with anaerobic digestion of the sludge. This sludge is approximately 4 to 6 percent solids when applied to the land.

Municipal solid waste (collected from city residents by an innovative mechanical loading system) is transported to the shredder plant located approximately 2.5 km (1.5 mi) from the city's geographic center. All incoming wastes are shredded to approximately 10 cm (4 in) or smaller particles. After shredding, most of the ferrous metals (about 60 percent, or 4 percent of the total waste stream) are magnetically separated for resale.

Waste Application

Upon arrival at the site, refuse transfer vehicles proceed directly to the active application area. Shredded wastes are unloaded from the rear by hydraulic ram as the truck moves slowly forward (see Figure 47). Wastes form a windrow about 2 m high by 2 m wide by 244 m long (7 ft by 7 ft by 800 ft), which is then spread by the cultivation equipment. Equipment used is a Buffalo Bomag MPH-1 soil stabilizer with a front-mounted blade for spreading (Figure 48).

A rototiller-like unit (Figure 49) is at the rear of the Bomag MPH-1. This unit mixes the shredded waste into the top 25 cm (10 in) of soil. A conventional tractor pulling a heavy roller follows to pack the soil. This rolling is performed to minimize wind erosion of the loosened soil. Figure 50 is a closeup of the field before (left side) and after (right side) mixing by the Bomag.

A second mixing is performed at a later date. This generally occurs 3 to 6 mo following application, and has two purposes. First, by remixing the soil/refuse, biodegradation is accelerated. Second, even with rolling, some wind erosion of the surface soil occurs. This exposes refuse, which is unsightly and retards biodegradation. Timing of the second "plowing" is established by a visual examination of the site surface and by dipping under the surface to observe the extent of decomposition obtained.

Loading rates ranging from 78 to 278 t/ha (35 to 124 tons/ac) have been applied. Operators are still attempting to determine the optimum loading rate suited for the particular soil conditions. Currently, the average loading rate is on the order of 112 t/ha (50 tons/ac). More time will be required

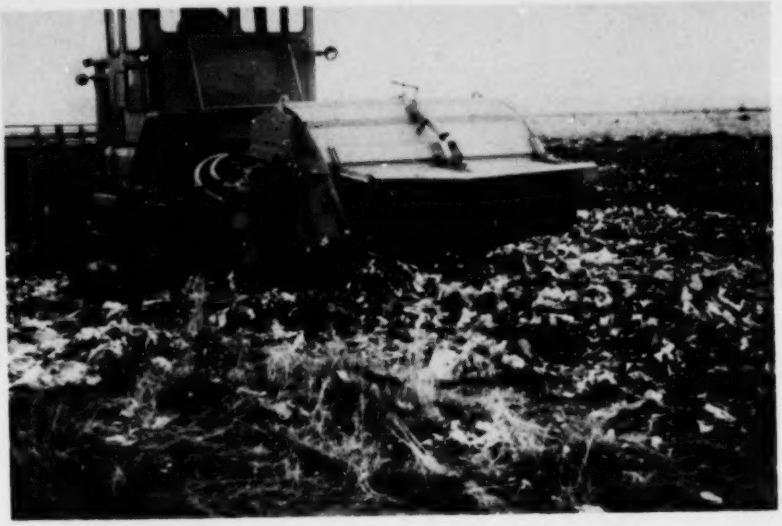


Figure 48. Buffalo Bomag soil stabilizer in operation.

Figure 49. Soil stabilizer roto-tiller unit.

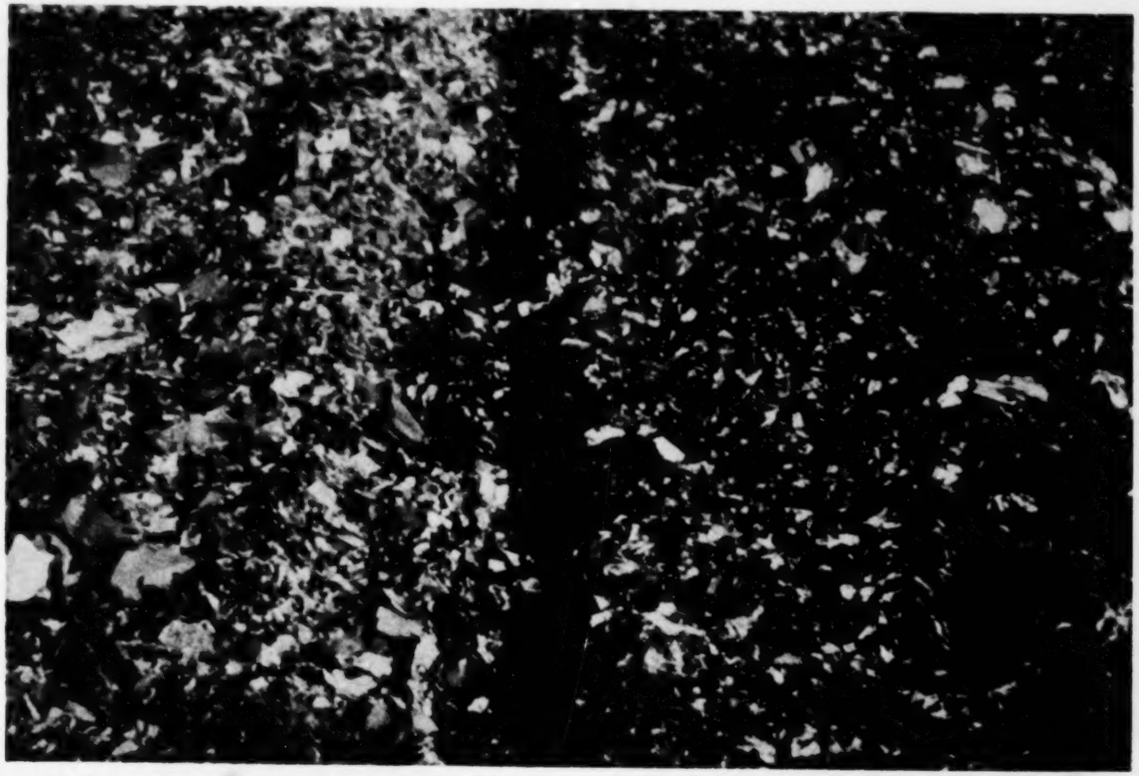


Figure 50. Applied refuse - Odessa site. Left side - before mixing, right side - after mixing.

to determine the optimum rate. This determination will be based on the productivity of seeded grasses.

Since a major goal of this program is to enrich the soil and increase its water-holding capacity, with disposal of wastes essentially a secondary goal, each portion of land receives only a single waste application. This will maximize the land area involved in the soil enrichment program.

Wastes are applied year round, except for the few occasions when rain makes the area too muddy to work. From the initial application in the summer of 1974, to late 1976, a total of 41 ha (101 ac) have been land cultivated. No fertilizers or other soil amendments have been added to the cultivated land. The initial 12.5-ha (31-ac) application area was treated with herbicides 2-4-5T and 2-4D after waste application to control tumbleweed growth.

Environmental Factors

Odessa has a well-equipped laboratory that has been used for wastewater treatment plant monitoring. Procedures are currently being developed to utilize this laboratory for the soil enrichment program. Soil and plant samples will be analyzed for pesticide and heavy metal content, using a gas chromatograph and an atomic absorption spectrophotometer. Total organic carbon levels in the soil will also be measured. In the spring of 1977, a study was initiated to identify pathogens that may be present in the waste treated soils, although preliminary results obtained earlier did not detect pathogenic bacteria and viruses. However, considerable additional work is planned.

Baseline conditions for soil and vegetation are established by sampling from a small, 0.2-ha (0.5-ac) control plot maintained near the active land cultivation site.

No monitoring wells exist or are planned at or near the site, and no monitoring of groundwater or surface water is performed. Surface water is found only intermittently in Monahan's Draw, which is remote from the site; thus surface water contamination is unlikely to occur. Since groundwater lies 27 m (90 ft) below the surface and there is little rainfall, the city does not feel groundwater monitoring is warranted.

The planned monitoring program, when fully operational, will determine the safety of vegetation as cattle feed. It will also determine the fate of heavy metals and pesticides in the applied wastes.

Field Sampling and Chemical Analyses

Both surface soil (0 to 15 cm) and vegetation samples were collected from the control and refuse-treated plots approximately 8 mo following waste incorporation. The refuse application rate was 112 t/ha (50 tons/ac). The plots had received no fertilizer or pesticide. Figure 45 illustrates the field layout and sampling locations, as marked by X's. The vegetation collected in the field included wild geranium (Erodium circutarium) and buckwheat (Eriogonum annum). Results are summarized in Tables 33 and 34.

TABLE 33. SOIL CHEMICAL CHARACTERISTICS FROM THE CONTROL AND REFUSE-TREATED PLOTS AT ODESSA, TEXAS

Parameter*	Control	Treated
pH	7.65	7.63
EC, mmhos/cm	0.61	2.12
TKN, %	0.043	0.066
Org. C, %	0.41	0.69
	- - ppm - -	
Ortho-P	22.5	25
Na	110	122
B	<0.2	0.25
Mn	22.5	33.1
Mo	0.05	0.05
Zn	1.8	7.2
Pb	0.09	0.12

*Electrical Conductivity (EC) and B (μg/ml) were measured in the saturation extracts; other elements in ppm (μg/g) were determined in 0.1N HCl extracts.

Land cultivation of shredded municipal refuse resulted in appreciable increases in soluble salt (EC) content and HCl-extractable manganese and zinc concentrations in the surface soil (Table 33). The increases in TKN and organic carbon levels appeared to be insignificant. The data suggest that land cultivation at Odessa has not resulted in significant changes in soil chemical properties and availability of plant nutrients. The concentrations of the selected trace elements and soluble salts in the refuse treated soil were not elevated and should not pose phytotoxicity or water pollution problems.

Plant analyses show slight increases in boron content of wild geranium, and in sodium, manganese, and lead contents of buckwheat (Table 34). There were no differences in nitrogen and phosphorus levels in plants grown in the control and refuse-treated plots. It is concluded that wild geranium and buckwheat

TABLE 34. ANALYSES OF WILD GERANIUM AND WILD BUCKWHEAT GROWN ON CONTROL AND REFUSE-TREATED PLOTS AT ODESSA, TEXAS

	Wild Geranium		Wild Buckwheat	
Element	Control	Refuse	Control	Refuse
	- - % - -		- - % - -	
N	3,46	4,27	2.31	2.27
P	0.28	0.39	0.40	0.55
	- - µg/g - -		- - µg/g - -	
Na	550	525	650	785
B	6	25	15.9	17
Mn	32.1	36.7	25.4	32.5
Mo	2.0	2.0	0.50	0.50
Zn	68.5	67.3	56	62.3
Pb	5.6	5.7	4.2	6.4

grown at the refuse disposal site for the first year are safe for consumption by cattle.

Waste Storage

No facilities for waste storage are provided. For most of the year, land cultivation is not interrupted by inclement weather. When weather conditions or other causes, such as equipment breakdown, preclude land cultivation of the wastes, all wastes are transported to the city's sanitary landfill for disposal. Equipment failures cause such diversions more often than does weather.

Equipment Used

Equipment available at the land cultivation site is a Buffalo Bomag MPH-1 soil stabilizer, the primary waste application/cultivation tool. A standard Farmall tractor, a tandem disk, and an 816-kg (1,800-lb) roller are also available to back up the Bomag in case of short breakdowns, and to compact soil behind the soil stabilizer. A conventional farm seeder is available to sow grass seed in the prepared soil.

Personnel

Currently, three full-time men staff the cultivation site: two operators and the foreman. Operator shifts are staggered to allow the application and cultivation activities to extend from 7 to 11, five days per week.

Site Economics

The city of Odessa has estimated costs for the fiscal year ending September 30, 1976, for both the land cultivation (soil enrichment) and sanitary landfill operations. These costs are summarized below:

	Cost (in $ per ton)	
Item	Land Cultivation	Landfill
Site operation & maintenance	1.16	3.62
Transport-shredder to site	1.56	1.63
Shredding	3.18	3.18
Total	5.90	8.43

Costs for the land-cultivation program are based on two men at the site: one operator and one foreman.

Table 35 presents cost estimates prepared by the city of Odessa for operation of a total soil enrichment program, cultivating 90 percent of the refuse, plus estimated capital costs for a 5-yr period. On an annual basis, operating costs are estimated at $386,705, and amortized capital costs at $24,830, for a total of $411,535. No interest rate was used in developing the amortized capital costs. Odessa generates approximately 75,000 tons of solid waste annually, which yields unit costs for the land cultivation operation of $5.49/ton ($411,535 divided by 75,000 tons). It is not clear if these estimates include amortized capital costs for the soil stabilizer. Since the purchase price for this piece of equipment is approximately $70,000, its omission would be significant.

Planned Final Use of Site

After the seeded ranch grasses have become well established on cultivated plots of land, and if laboratory analyses show that grasses do not uptake hazardous levels of any compounds, these plots will be returned to the land owner for cattle grazing. Odessa's soil enrichment program, once well established, will consist of a continuous cycling of land. Untreated ranch land will be leased for land cultivation of wastes, and land that has had waste application and has been revegetated will be returned to productive use.

Public Response to the Land Cultivation Operations

From the beginning, the soil enrichment program was positively presented to the residents of Odessa and surrounding ranchers. Emphasis was placed on the beneficial aspects of improving the land's grazing capacity while supplementing waste disposal at sanitary landfills. The land cultivation activities have been favorably received by the populace. There has been strong local support for the program, with essentially no opposition expressed.

Problems Encountered

Herbicide application on waste treated land was not fully successful in controlling tumbleweed growth. Nearby residents have complained about the tumbleweeds migrating onto their lawns. The city is attempting to physically control tumbleweed growth, but this is a very difficult task.

The treated plots, 2½ yr after refuse application, have other problems. For instance, the arid conditions retard microbial activity. Therefore, large cardboard pieces are still only partially decomposed (but will biodegrade with time). More serious problems exist with respect to plastics, leather, and metals. Only about 60 percent of ferrous metals and no nonferrous metals are removed at the shredder. The remaining metals, and

TABLE 35. ESTIMATED COSTS, TOTAL SOIL ENRICHMENT OF SHREDDED ODESSA REFUSE*

Operating Costs

Item		Annual Costs
• Personnel (includes benefits)		$ 145,965
• Supplies & materials		33,033
• Building maintenance		2,150
• Improvements maintenance		4,110
• Shop & plant equipment maintenance		26,557
• Equipment rentals		133,653
• Other services & charges		41,237
	Total	$ 386,705

1976 to 1981 Capital Expenditure Estimates

Item		Cost	Expected Life
• Landfill improvements		$ 19,550	5 yr
• Equipment rentals		196,300	
pickups		(4,300)	5 yr
air compressor		(8,000)	10 yr
large dozer		(155,000)	10 yr
tractor		(11,000)	10 yr
shredder sweeper		(8,000)	10 yr
waste spreader		(10,000)	10 yr
radio equipment		2,200	
	Total	$ 218,050	Amortized annual capital cost= $24,830

*With backup emergency landfill.

all plastics and leather, are land cultivated. Items such as sections of garden hose and old shoes are visible. If returned to cattle grazing, this land presents a potential for "hardware disease" problems.

Wind erosion of the cultivated area has been experienced; however, this has also been a problem throughout the Odessa region during the spring of 1977. There has been little blowing of the applied refuse. No significant fly or rodent infestations have been reported.

Also, an equipment problem has caused several periods of inactivity on the land cultivation site: the soil stabilizer has experienced frequent mechanical failures, some of which have resulted in cessation of operations for several days. The city has expressed an interest in more reliable equipment, but has had no success in locating such equipment.

MICHIGAN

Summary

Company X operates a large semi-chemical pulp and paper mill in Michigan. In 1976, the company applied a portion of the secondary sludge from its activated sludge wastewater treatment plant to a few hundred acres of land to be used for new tree farms of hybrid aspen and poplar. This sludge application served two basic functions: (1) to dispose of the sludge without causing odor, and (2) to provide low-cost fertilizer and soil conditioner for new growth trees.

The operation has been very successful to date. Subsurface sludge application has not caused any problems, and the sludge has shown positive fertilizer value.

History of Land Cultivation Activities

Land cultivation activity was initiated in response to two occurrences: regulatory requirements by the state of Michigan, and the energy crisis. In 1970, when the company was designing a secondary treatment plant, the state of Michigan Department of Natural Resources informed Company X that it would be required to dispose of its sludge without any odor (i.e., that landfilling and lagooning would be excluded as disposal techniques). This led to the purchase and installation of a large Dorr-Oliver fluidized bed incinerator for sludge disposal. However, the plant started in December 1972, after the effects of the energy crisis inflated the costs for fuel oil, and management realized that a less energy-intensive method should be explored. Thus Company X began experimenting with land cultivation of the sludge, not only to dispose of the solids but to take advantage of their nutrient value.

The experimental project was successful and, in the spring of 1976, was expanded to a large pilot-scale program. The expanded program involved the cultivation of 2.7 to 9 dry weight t (3 to 10 tons) of sludge per day on several thousand acres of land owned by the company.

Site Description

The sludge is spread on many different plots totaling a few hundred acres of tree farmland, all owned by Company X. In total, the company owns over 19,600 ha (49,000 ac) in Michigan (valued at \$200 to \$600/ac) of which 1,200 ha (3,000 ac) are planned for ultimate use under the pilot-scale sludge cultivation program.

Topography and Vegetation--

The various cultivation plots are quite different in topography, vegetation and soil type, drainage patterns, and other characteristics. Topography ranges from flat to rolling hillsides; natural vegetation from sod and natural grasses to moss; soil types from excessively drained, sandy soils to poorly drained, heavy clays. Surface drainage patterns vary from plot to plot, but most areas drain to nearby ditches or streams. The amount of runoff is closely related to soil type and vegetative cover.

Climate--

The region has severe winters, with moderate snow accumulations and low temperatures. Average daily winter highs are in the range of -2° to -6°C (20° to 30°F). Frost conditions exist from 5 to 30 cm (2 to 12 in) deep, depending on temperature and the prevalence of insulating snow cover. Summers are mild with average high temperatures of 20° to 30°C (70° to 80°F). Precipitation averages about 79 cm (31 in) per year, predominantly in the spring and summer months. Winds are often quite strong during winter and spring. Climatic data are summarized in Table 36.

Site Preparation--

Site preparation was conducted at only a few fields, where heavy sod cover required disking prior to spreading activities. No berms or other types of runoff protection were provided, as authorities feel that subsurface injection eliminates the need for this control.

Related Studies

Because the sludge is being used on productive tree farmland, the potential beneficial or adverse effects of these high nutrient content solids on tree growth are critical. To analyze these effects, six independent studies are currently in various phases of completion:

TABLE 36. SUMMARY OF CLIMATOLOGICAL DATA: GRAND RAPIDS, MICHIGAN

	Precipitation	Temperature		Winds
Month	Normal	Maximum	Minimum	Mean Hourly Speed
January	4.9 cm (1.9 in)	0°C (31°F)	-8°C (17°F)	18.7 kmph (11.6 mph)
February	4.4 (1.8)	0 (32)	-9 (16)	17.5 (10.9)
March	5.8 (2.3)	5 (42)	-4 (24)	18.7 (11.6)
April	7.5 (2.9)	14 (57)	2 (35)	18.2 (11.3)
May	8.8 (3.5)	20 (69)	7 (45)	17.2 (10.7)
June	8.4 (3.3)	26 (79)	13 (56)	15.0 (9.3)
July	6.9 (2.7)	29 (84)	16 (60)	13.2 (8.2)
August	6.9 (2.7)	28 (83)	15 (58)	13.8 (8.6)
September	7.6 (3.0)	24 (74)	10 (50)	14.8 (9.2)
October	6.6 (2.6)	17 (63)	4 (40)	16.2 (10.1)
November	6.3 (2.5)	8 (46)	-2 (28)	17.9 (11.1)
December	5.2 (2.0)	1 (34)	-7 (20)	16.9 (10.5)
Year	79.2 (31.2)	14 (58)	3 (37)	16.6 (10.3)

- Starting in 1975, Company X began experimenting with sludge application on fields to be planted in aspen and poplar. Initial results on trees grown from seed showed height increases of 30 to 40 percent in sandy soil, but no improvement in clay soil. The latter showed poor nutrient release and organic matter breakdown.

- Sludge fertilization experiment on corn were conducted by Company X. Fields with low nitrogen fertilization yielded 75 bushels/ac; with moderate commercial fertilization, 83 bushels/ac. With sludge application rates that provide high nitrogen levels (448 kg/ha, or 400 lb/ac) the corn yield was 92 bushels/ac.

- Company X is also experimenting with sludge application on 3- and 4-yr-old natural regeneration aspen to determine whether the nutrients in the sludge can be made available to a more mature tree.

- Michigan State University is currently conducting a study on the effect of sludge application on soil properties and the yield and quality of corn and soybeans.

- Experiments are being carried out to determine possible effects of very heavy sludge loading rates on groundwater quality. Loading rates ranged from 7 to 54 t/ha (3 to 24 tons/ac). After 1 yr of testing, no adverse effects have been detected.

- The U.S. Forest Service is experimenting with spray application of sludge on 35-yr-old red pines.

Waste Characteristics

The sludge is processed by the following units at the wastewater treatment facility before it is applied to the land:

Unit	Effluent % Solids
• Secondary clarifier	1
• Gravity sludge thickener	2
• Solid bowl centrifuge without chemical conditioning	5

Although the centrifuges are capable of achieving a solids concentration of 10 percent (with polymer addition) for incineration, this degree of dryness is not required for land application. The 5 percent solids sludge is preferred because it can be pumped and transported as a liquid.

Company X performed a series of sludge analyses in 1975 and 1976, which are summarized in Table 37. According to these analyses, the sludge is 38 percent protein, and has a slow nitrogen release. Breakdown of the sludge in the soil is similar to that of any protein matter. The company generates approximately 12.2 t (13.5 tons) dry weight per day of secondary sludge. Under optimal conditions, all the sludge is land cultivated; otherwise, as little as 3.2 t (3.5 tons) is cultivated and 9 t (10 tons) is incinerated.

Waste Storage/Transportation

A total of 151 m^3 (40,000 gal) of sludge storage capacity - sufficient only for overnight storage - is provided at the treatment plant by three tanks. The tanks, as well as a circulating pump, were available as surplus equipment from another portion of the mill.

The transportation and spreading operation was initially done by a private contractor, but is now operated by company personnel. Two large tank trucks of 32- and 38-m^3 (8,500- and 10,000-gal) capacities are used for hauling the sludge from the storage tanks to the fields (a maximum distance of 32 km, or 20 mi, from the mill). One driver is currently required for hauling. He drops one full tank trailer of sludge at the field and returns to the mill for the other one, as the sludge applicator vehicle nurses off the trailer. This procedure is continued throughout the day for a maximum of eight tank truckloads in a 10- to 12-hr working day.

Waste Application

The sludge is subsurface injected into the field by a "Big Wheel" sludge applicator vehicle. This vehicle is specifically designed for field application of liquids, and has high flotation provided by 1.2-m (4-ft) wide tires. Once the full tank trailer has been dropped near the spreading site, the Big Wheel takes on its 6-m^3 (1,600-gal) load of sludge. With the aid of the subsoiler attachment on the rear, the Big Wheel injects the sludge from 2.5 to 10 cm (1 to 4 in) below the surface in the small furrows created by the mechanism. The vehicle moves across the field at about 8 km/hr (5 mph), injecting its load in about 3 min, and returns to the trailer to refill. Loading rates average about 188 m^3 or 8.9 t dry solids/ha (20,000 gal or 4 tons/ac). This provides approximately 560 kg/ha (500 lb/ac) of total nitrogen, or 0.11 t (100 lb/ac) of available nitrogen. The Big Wheel makes about four passes over the same ground to achieve this loading, and the fields are treated only once prior to planting. One driver operates the Big Wheel with occasional supervision from the company staff.

TABLE 37. SLUDGE ANALYSES - MICHIGAN SITE

	Concentration (mg/kg)				
	Date				
Parameter	1/15/76	3/11/75	5/13/76	5/14/76	5/17/76
Org-N	63,550	61,800	47,432	48,805	47,068
NH_3	2,350	1,330	7,532	8,139	7,342
NO_3	1	1	3	3	3
NO_2	0.5	1.5	2	2	2
P	8,310	11,000	6,199	5,987	7,317
K	3,300	3,900	2,283	2,449	2,371
Ca	16,000	17,000	22,207	22,074	22,761
Fe	2,700	2,800	2,750	3,346	3,524
Mg	1,700	2,800	4,670	4,840	4,793
Mn	650	710	908	1,007	1,020
Na	2,400	3,900	4,317	4,396	4,040
Ar	--	--	0.65	0.71	0.83
B	38	41	62	9	41
Cd	--	--	4	4	4
Cr	42	41	32	41	35
Cu	30	25	36	41	43
Pb	--	--	<0.05	<0.05	<0.05
Hg	1.0	0.1	1.07	2.79	0.27
Ni	--	--	--	--	--
Se	--	--	<0.25	<0.25	<0.25
Zn	180	220	--	--	--

Although the winter of 1976 was cold, with little insulating snow, the Big Wheel was still in operation through December 1976. Its subsoiler mechanism was able to break through the ground, which was frozen about 10 cm (4 in) deep. With the accumulation of snow, the company experimented with sludge spraying on the surface, followed by plowing of the site as soon as farm equipment could work the soil in the spring. There were no problems with odor or runoff during the spring melt.

For experiments on grown trees, the Big Wheel is used with a spray attachment. The truck drives down an access road or narrow cleared path and sprays the sludge laterally onto the trees and soil.

If the sludge is only used on ground that is yet to be planted, a 15-yr time lapse will be required for the trees to mature and be harvested before more sludge can be applied to that land. However, program managers are confident that the sludge can be used to advantage on young trees as well, and that a plot of land will then be able to accept more than the initial 9-t/ha (4-ton/ac) dosage. The major difference in spraying young trees is that the application procedure must be carefully monitored to avoid odor before the sludge is plowed into the soil. Care must also be taken to avoid damaging the trees.

Environmental Factors

Two of the experimental test plots are closely monitored with a network of shallow wells to check any effects of sludge application on groundwater quality. Parameters measured include NO_3, TN, pH, conductivity, and depth to the groundwater table.

As of late 1976, the state of Michigan was initiating guidelines and monitoring requirements for industrial sludge spreading programs. Starting in the summer of 1977, quarterly reports are being required on quantity of sludge applied, incidence of runoff, odor occurrence, and other problems.

Economic Summary

Table 38 summarizes anticipated costs under full-scale operation to be initiated in 1977 or 1978. Company X paid \$58/ton dry weight to a private contractor to have the sludge hauled and spread. The costs in Table 38, estimated by SCS, reflect the company's takeover of the entire operation. Actual company costs are not available. As shown, existing pretreatment represents a large portion (over 42 percent) of the overall program costs.

TABLE 38. ANTICIPATED COSTS FOR MICHIGAN SLUDGE APPLICATION PROGRAM*

	Cost (1975 $)			
		O&M	Total	
Item	Capital	($/Yr)	($/Yr)	($/$m^3$)†
Pretreatment	750,000	65,000	140,000	1.48
- clarifier				
- thickener				
- 4 centrifuges				
Hauling				
- 2 tractors	60,000	5,000	13,000	2.64
- 4 tankers	120,000	2,000	18,000	3.65
- 2 drivers (including fringe benefits)	--	42,000	42,000	8.52
			73,000	
Spreading				
- 2 Big Wheels	100,000	12,000	43,000	8.73
- 2 drivers	--	42,000	42,000	8.52
			85,000	
Maintenance				
- 1 pickup truck	6,000	2,000	3,000	0.61
- 1 mechanic	--	22,000	22,000	4.46
- tools & shed	10,000	--	1,500	0.30
			26,500	
Monitoring				
- 20 wells	1,000	--	500	0.10
- sampling & analysis	--	5,000	5,000	1.01
TOTAL	$1,047,000	$197,000	$330,000	$66.95

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*SCS estimate.

†Assume 13.5 t/day, 365 days/yr.

Planned Final Use of Site

All sludge spreading sites are now and will continue to be used as hybrid poplar and aspen tree farms. There are no plans to use the site for any other purpose.

Public Response

A well-organized public information program was initiated prior to sludge cultivation activities. The program emphasized that the sludge was to be subsurface injected to minimize odor, and that the plots would look like normal plowed fields. Company X consulted with the following groups before program implementation:

- The township supervisor
- County agricultural agents
- The county public health director
- State water resource, air pollution, and solid waste management districts
- U.S. Soil Conservation Service.

In essence, all concerned people were aware of the program and consented to its operation. As a public relations aid, guided tours are conducted in some areas of the farm.

Problems Encountered

The only problem encountered was occasional summer odors when sludge spraying was first tried. With subsurface sludge injection, this problem has been eliminated.

SECTION 4

NONSTANDARD DISPOSAL OF HAZARDOUS WASTES

OVERVIEW

Modern industrial activities produce a large variety and quantity of hazardous wastes. Conventional disposal techniques for these wastes include disposition in impoundments and in chemical and sanitary landfills, and incineration. However, there is a growing interest in nonstandard disposal techniques that can provide for a practical utilization of the waste materials.

The trend toward utilization, or nonstandard disposal, has been prompted by several factors. Conventional, or standard disposal techniques have, in several instances, resulted in adverse environmental effects such as groundwater contamination and air pollution. In such cases, alternatives have been sought that would avoid these adverse effects. Some industries have found that acceptable disposal sites - such as landfills - within economical transport distance are being closed, thus requiring an alternative method to be found for hazardous waste disposal. In other cases, the costs associated with standard disposal have increased substantially. This may be caused by increasingly strict requirements to control emissions, or by escalating energy costs. Another factor that has led to waste utilization is the growing awareness that one industry's wastes may be another industry's resource. In these cases, the wastes may be substituted for virgin materials. This provides the waste generator with a low-cost, or possibly even revenue-producing, method of waste disposal while at the same time giving the user a source of supply at a reduced cost. An example of this is the use of boiler slag as an aggregate in construction projects.

It should not be assumed that nonstandard disposal is free of problems. Environmental degradation may still result, but the overall impacts may be lessened since contaminants are often spread over a larger geographical region due to utilization of the wastes. For this reason, it is imperative that the interactions between the waste at its site of use and the surrounding environment be fully understood.

Section 4 deals with some of the nonstandard disposal techniques available to industry. The types of hazardous wastes that have been disposed in a nonstandard manner are first discussed, followed by a discussion of disposal techniques. These techniques essentially involve utilization of the waste, thereby providing a useful product as well as a method of disposal.

WASTE TYPES AND NONSTANDARD DISPOSAL TECHNIQUES

Fly Ash

Construction Uses--

Current use patterns for fly ash indicate its main application is as a pozzolanic additive to Portland cement concrete where its natural cementitious properties can bring about a genuine savings in costs (33, 34). Other applications include uses as a roadbed or railroad bed stabilizer, filler for asphalt mixes, lightweight aggregate, oil well grouting, and as mine subsidence. Because of its fire- and skid-resistant characteristics, fly ash also is the main ingredient for mine fire control purposes and in anti-skid winter roads.

Agricultural Uses--

Major chemical constituents (30 to 40 percent) of fly ash are Si, Al, Fe, Ca, and Mg (35). It is also rich in trace elements such as B, Mo, and Zn. Many researchers have reported that fly ash can be used as a micronutrient supplier to correct deficient soils and enhance agricultural production (35, 36, 37, 38, 39, 40). When fly ash is alkaline in a reaction, it can be utilized as a supplementary source of agricultural limestone. For example, the neutralizing capacity of fly ash from the Mojave generation station in California is from 35 to 50 percent, the same as commercial agricultural limestone (35). Furthermore, the use of fly ash as a soil amendment would alleviate problems associated with Al and Mn toxicities to plants in acid soils. Adams et al.(41) encouraged using fly ash as a neutralizing material to reclaim coal mine spoil and refuse bank.

Caution should be taken with the use of fly ash in agriculture. Recent investigations indicate that fly ash may contain carcinogenic compounds. Agricultural use should then be limited to applications where these compounds do not enter the food chain or present health hazards to workers.

Miscellaneous Uses--

When concentrations of certain high value elements in fly ash are great, the ash can be recycled to recover the element. For example, Brackett (33) reported the use of fly ash to recover vanadium.

Bottom Ash and Boiler Slag

These wastes can be used for construction purposes because of their pozzolanic characteristics and their natural cementitious properties (33). For example, bottom ash and boiler slag are used in place of cement in concrete products, as lightweight aggregate, as fill material for roads and construction sites, as a stabilizer for road bases and parking areas, and as filler in asphalt mix.

Steel Slag

Some useful characteristics of the numerous steel slags include durability, resistance to abrasion and corrosion, and fire and skid resistance. Depending upon particle size, steel slag can be utilized as follows (42):

- Construction Uses
    - Pozzolanic additive to Portland cement concrete
    - Base material for mineral wool
    - Lightweight aggregate
    - Railroad ballast
    - Material for pipe backfill
- Wastewater Treatment Uses
    - Material for septic tank absorption beds
    - Trickling filter medium

Chemically, steel slag is composed mainly of calcium and magnesium alumino-silicate. It also contains smaller amounts of other elements such as Fe, Mn, S, and P. Because of its strong alkalinity and high Ca content, steel slag has been utilized as a liming material (43).

Leather Tanning and Finishing Industry Wastes

Following is a list of the types of potentially hazardous wastes generated by the leather tanning and finishing industry and their potential beneficial uses:

Waste Stream	By-Product Uses
Solvent-based finished residues	Solvent recovery
Blue trim and shavings	Fertilizer Hog feed supplement Glue
Leather trimmings	Glue Craftsman of leather articles

With the exception of solvent recovery, by-product utilization of potentially hazardous waste is volatile and dependent upon location. The major type of potentially hazardous waste sold is blue trim and shavings. These are sold to producers of fertilizer (supplying principally N and, to a lesser degree, P, K, Ca, Mg, Cu, and Zn) used in citrus groves and other orchards (18). Similarly, some tanneries also sell blue trim and shavings for use as a hog feed supplement (supplying proteins, vitamins, and trace elements such as Cr, Cu, and Zn) and in the manufacture of glue. Occasionally, finished leather trimmings are sold to glue manufacturers and to local craftsmen or foreign countries for the manufacture of small leather goods.

Pulp and Paper Mill Wastes

Organic by-products recovered from spent cooking liquors include turpentine, tall oil, alcohols, dimethyl sulfoxide, vanillin, and yeast (44). Yeast production shows great potential in by-product utilization of spent sulfite liquor. The yeast cells, which grow rapidly, contain large amounts of proteins and vitamins that can be used as food supplements. These can be used directly in the manufacture of roofing felts and in thermal insulation materials. The soluble sugars in the pulp washer water are concentrated in evaporators to recover a molasses-type cattle feed by-product.

Phosphoric Fertilizer Industry Wastes

Wastes from the phosphoric fertilizer industry contain large amounts of gypsum and fluoride effluents. The recrystallization under controlled conditions produces plaster and construction blocks (44). Production of sulfur, sulfuric acid, and cement constitutes other possible uses of these wastes.

Waste Sulfur and Sulfuric Acid

Surplus sulfur and sulfuric acid can be used beneficially in agricultural practices for reclaiming sodium-affected calcareous soils, increasing the availability of phosphorus and certain micronutrients, e.g., Fe, Zn, and Mn, treating alkaline and ammoniated irrigation water, and controlling certain weeds and soil-borne pathogens, e.g., *Phymatotricum omnivorium*, *Helminthosporium turcicum*, *Cyrisdon dactylon*) (1, 10). Other miscellaneous uses of waste sulfuric acid include dust control on alkaline dry lake beds (1), seed scarification to break dormancy (45), crop desiccation, control of algae and aquatic plants, and soil crusting control (46).

Plating Industry Wastes

The reclamation of chemicals from rinse waters produces economic benefits. Chromic acid is recovered by evaporation and ion exchange (44). Ion exchange is also used in the recovery of high value metals such as gold, silver, and platinum. The demineralized water produced in this process may be good to reuse for cooling and for some processing.

Pharmaceutical Wastes

Fermentation residues from the pharmaceutical industry contain relatively small amounts of the plant nutrients (2.50 percent N, 2.58 percent Ca, and 0.47 percent Zn). The wastes also contain P, K, Fe, and Mg and about 2.70 percent fat. Pharmaceutical wastes can be excellent supplements for animal feed (47), and can also be used as fertilizer, principally supplying N and Zn to agronomic crops (48).

Used Crankcase Oils

These wastes can be reprocessed to produce low-grade oil (49) or can be used as an auxiliary fuel (50).

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APPENDIX

METHODS FOR SAMPLE PREPARATION AND ANALYSIS

The following procedures were standardized for the preparation and analysis of soil and plant samples received from the field investigation sites.

SAMPLE PREPARATION

Soil samples were air-dried (temperature <40°C), ground up to pass through a 2-mm sieve, and stored until analysis. A portion of the air-dried soil was placed in a moisture can and dried at 110°C for 24 hr. This portion was used later for the expression of concentration on an oven-dry basis.

Plant samples were washed with P-free soap (Ivory Snow), rinsed in deionized water, blotted, and dried in a 70°C forced-draft-oven for 48 hr. The samples were then ground up in a stainless steel grinder (<20 mesh) and stored in plastic vials.

Approximately 2 g of air-dried soil were shaken thoroughly in 20 ml of 0.1 N HCl for 1 hr. The mixture was then centrifuged and filtered and the filtrate analyzed for orthophosphate, sulfate, and trace elements (including heavy metals). The concentration found in the HCl extraction is presumably an indication of the bioavailability or potential mobility of the element. Separate aliquots of soil samples were required for the analyses of total nitrogen, organic carbon, pH, and oil content (where necessary).

The water extraction procedure used was that outlined by Richards (1). A saturated paste was made by gradually adding deionized water to the air-dried soil and thoroughly mixing them. The paste was allowed to stand overnight. The following day the paste was placed on a Richards funnel and an extract obtained under suction. This extract was used to analyze electrical conductivity, boron, chloride, and occasionally sodium, potassium, calcium, and magnesium. The concentration found in water extraction is presumably readily leachable or available for plant uptake.

Approximately 0.5 g of plant sample was digested in 5 ml of concentrated HNO_3-$HClO_4$ mixture (5 = 2 by volume). After the digestion was complete, the mixture was diluted with deionized water and analyzed for nutrients and trace elements (including heavy metals).

ANALYTICAL PROCEDURES*

Soil pH (1:1): Glass electrode (2)

Organic Carbon Dichromate - Sulfuric acid method (2)

Total Kjeldahl Nitrogen or Total Nitrogen - Semimicro Kjeldahl method (3)

Heavy metals - Atomic absorption spectrometry

Calcium and Magnesium - Atomic adsorption spectrometry

Sodium and Potassium - Flame photometry

Chloride - Mercuric nitrate procedure (4)

Sulfate - Turbidimetric method (3)

Boron - Curcumin method (4)

Selenium - Hydride method (2)

Molybdenum - Atomic absorption spectrometry

Phosphorus - Colorimetric procedure using $SnCl_2$ as a reducing agent

Oil and Grease - Soxhlet extraction method (4)

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*The following analytical procedures were used to test the sample plants and soils.

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